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Capacity Utilization and Measurement of Agricultural Productivity *cat/sta*

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Abstract

The failure to consider variations in capacity utilization can distort productivity measurement. This report develops a theoretical model of capacity utilization and productivity measurement, estimated for 1949-87, for the U.S. farm sector. Adjusting for capacity utilization reduced observed productivity growth by 17 percent. Public production subsidies and export demand may explain these results.

Keywords: Agricultural productivity, capacity utilization, quasi-fixed inputs

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Summary

The failure to consider variations in capacity utilization can distort productivity measurement for the U.S. farm sector. This report develops a theoretical model of capacity utilization and productivity measurement, which is estimated by full information maximum likelihood (FIML) techniques over the period 1949-87. Capacity utilization is the ratio of actual output to the level of output that minimizes shortrun average total cost. Primal- and dual-capacity utilization measures are developed together with a multifactor productivity index and adjusted for capacity utilization. Prior to 1981, capacity utilization measures were usually above 1 but also close to 1, findings which are consistent with those of the manufacturing sector. Capacity utilization fell well below 1 in the 1980's. Capacity utilization varies over time, with higher levels in the 1970's than in earlier or later periods.

An analysis of shadow prices for capital and self-employed labor indicated that a capital shortage prevailed in farming for most of 1949-80. In the 1980's, however, capital was in surplus. A self-employed labor surplus existed throughout the 1949-87 estimation period.

Disequilibrium, defined as the difference between the unadjusted and the adjusted productivity growth rates, accounts for more than 17 percent of observed productivity growth during the 1949-87 period. The observed average growth rate of unadjusted productivity was 2.009 percent per year, but adjusting for disequilibrium reduced this growth rate to 1.668 percent per year. The quantitative importance of disequilibrium was greater in the period's earlier years. However, the unadjusted and adjusted productivity indexes display similar periodic patterns. Adjusting for variation in the use of quasi-fixed inputs does not smooth observed short-term productivity shifts.

Unadjusted and adjusted productivity growth over time displayed similar patterns. Average unadjusted productivity growth generally fell until the late 1970's but increased sharply in the 1980's. Average annual unadjusted productivity growth declined from 1.980 percent per year for 1950-55 to 1.160 percent per year for 1971-80, but rose to 4.840 percent per year during 1981-87. Volatility in growth rates appears to have increased in the latter part of the estimation period.

Adjusted productivity growth averaged 1.280 percent per year from 1950 to 1955, but declined to 0.880 percent per year for 1956-70, before rising to 0.930 percent per year for 1971-80. For 1981-87, however, adjusted productivity growth averaged 4.740 percent per year, a marked increase.

Two factors appear to account for the significant effect of disequilibrium on observed productivity growth: large net production subsidies from the public sector and unexpected changes in export demand. Agricultural exports increased sharply in the 1970's but fell as dramatically in the 1980's.

The model appears to be well specified. Most parameter estimates are statistically significant. Corrected R^2 and Durbin-Watson statistics are also encouraging. Little autocorrelation was evident, and the model explained a substantial part of the variation in the data. Alternative price equation and multioutput specifications yielded essentially the same results, together with high t-statistics.

Capacity Utilization and Measurement of Agricultural Productivity

James H. Hauver

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Introduction

Multifactor productivity is a measure of the relationship between output (goods and services) and all inputs used in their production, such as labor, land, and capital. Productivity is typically expressed as a ratio of outputs to inputs. An improvement in productivity means that more output can be obtained for a given input, or alternatively, that the same level of output can be obtained with fewer inputs.

Empirical estimation of productivity changes requires the imposition of numerous strict assumptions, about which economists disagree. Among the assumptions typically made is that the farm is in longrun, steady-state equilibrium. Since shortrun and longrun equilibrium is continuous, no dynamic adjustment process is required.

This assumption is clearly unrealistic. Certain factors in agricultural production have a quasi-fixed character, being fixed in the short run and variable only in the long run. Changing these quasi-fixed factors entails adjustment costs to the farm operator. Quasi-fixed factors include farm operator and unpaid family labor, farm machinery and structures, and possibly land. The inability to rapidly adjust fixed factors in the face of economic shocks means that some factors will be either underutilized or overutilized in the short run.

Moreover, the failure to consider variations in capacity utilization can distort productivity measurement. Observed productivity will be exaggerated during periods of rapid output expansion but understated during periods of contraction. Two factors peculiar to the agricultural sector are especially important. First, agriculture is vulnerable to production shocks arising from weather conditions, as well as plant and animal diseases. For instance, serious drought conditions prevailed in the Great Plains from 1953 through 1957, affecting wheat yields and output. In the latter phases of the drought, the Corn Belt was also affected, modestly reducing corn production. Shortages of water and feed led to premature liquidation of cattle herds. The corn blight of 1970 similarly diminished corn yields and production.

Second, the public sector provides a powerful stimulus to agricultural output through net production subsidies. These subsidies include price and income supports, disaster payments, payments-in-kind, marketing loans, loan interest rebates, tax benefits, tariffs and import quotas, and many other government intervention policies. In effect, such policies encourage farm operators to increase production beyond levels which would be optimal in an entirely free market. Ignoring the influence of capacity utilization will distort productivity measurement so that observed productivity changes will not accurately reflect true productivity changes.

Economists have consequently developed capacity utilization measures as a way to capture variation in factor use over time. By adjusting productivity measures for capacity utilization, one important source of distortion in productivity measurement can be removed.

Unfortunately, most existing capacity utilization measures are ad hoc measures, without an adequate foundation in economic theory. These include the Federal Reserve Board, McGraw-Hill, Wharton, and census measures, which are constructed from production and survey data. Using a somewhat different procedure, Dvoskin (1988) developed an excess capacity measure for the agricultural sector. Since none of these measures are built on an optimization framework, they have no clear economic interpretation.

However, researchers have recently developed and used new capacity utilization measures based on economic theory to adjust productivity growth for changes in capacity utilization (Berndt, Morrison, and Watkins, 1981; Berndt and Fuss, 1986; and Morrison, 1985, 1986). Such models distinguish between shortrun and longrun equilibrium by treating some inputs as variable and others as quasi-fixed.

This study applies these recent developments to agricultural productivity measurement, where some inputs are quasi-fixed while others are variable. We develop and compare two theoretically sound capacity utilization measures and assess their significance for observed productivity growth. Estimated shadow prices of quasi-fixed inputs are then used to derive adjusted productivity measures, which consider variations in capacity utilization.

Theoretical Framework

We employ the economic theory of cost and production to define a measure of capacity utilization and a measure of productivity growth adjusted for capacity utilization.

Since capacity utilization is a shortrun concept, it is necessary to consider the shortrun constraints facing the farm. Thus, it is inappropriate to employ cost functions or production functions in which all inputs are assumed to be instantaneously adjustable. We employ a quadratic shortrun variable cost function with two variable inputs and two quasi-fixed inputs.

The restricted or variable cost function is defined as:

$$(1) \quad G = G(w, X, Y, t)$$

where w is a vector of variable input prices, X is a vector of quasi-fixed inputs, Y is output, and t is time. The restricted cost function gives the minimum variable cost conditional on w , Y , X , and t .

Two properties of G are especially important for empirical work. First, the partial derivative of G with respect to w_j equals the shortrun, cost-minimizing demand for variable input j (v_j):

$$(2) \quad \frac{\partial G}{\partial w_j} = v_j.$$

Second, the partial derivative of G , with respect to the quantity of any quasi-fixed input, equals the negative of the shadow rental price of the quasi-fixed input:

$$(3) \quad \frac{\partial G}{\partial X_i} = -Z_i.$$

The shadow price of X_i is the reduction in variable costs incurred by having one more unit of X_i . In longrun equilibrium, $Z_i = q_i(r + \delta_i)$ where q_i is the asset price of quasi-fixed input i , r is the farm's discount rate, and δ_i is the depreciation rate.

The economic theory underlying traditional productivity measurement is closely related to the theory of cost and production. The production function $Y = F(v, X)$ is conventionally interpreted as a relationship between the flow of output and the flow of input services. A problem occurs when some of the inputs are quasi-fixed: the flow of services depends on the level of utilization.

Productivity analysts have handled this problem in several ways. One solution is to assume that service flows are proportional to stocks. Capacity utilization is then constant over time and, in particular, over the business cycle. But capacity utilization is known to vary over the business cycle.

An alternative approach is to multiply the stocks by an estimate of capacity utilization. However, this merely converts the problem from one of measuring services from quasi-fixed inputs (given the stocks) to one of measuring capacity utilization.

Service flows or capacity utilization cannot be readily observed, thus making their measurement difficult. The approach taken in the recent literature on temporary equilibrium is to dispense with the notion of service flows from quasi-fixed inputs altogether and to analyze production from the standpoint of stocks alone. Thus the production function is interpreted as a relationship between the flow of output and the flow of services from variable inputs applied to a stock of quasi-fixed inputs. Since the stock of quasi-fixed inputs is fixed in the short run, shortrun fluctuations in demand can be accommodated only by changes in the levels of variable inputs used in production.

Assuming longrun constant returns to scale (CRTS), it is reasonable to define the optimal level of output Y^* (for the given stock of quasi-fixed inputs) as the level of output which minimizes shortrun average total cost (SRAC). Capacity utilization can be defined as:

$$(4) \quad CU = \frac{Y}{Y^*}$$

where Y is actual output.

Capacity utilization, in this sense, is increased when more variable inputs are applied to the fixed stock of quasi-fixed inputs. When the firm is in longrun equilibrium under CRTS, variable input levels minimize SRAC at $Y = Y^*$ and $CU = 1$. This is illustrated in figure 1. When a greater quantity of variable inputs is applied to the stock of quasi-fixed inputs, $CU > 1$, and conversely $CU < 1$ when a lesser quantity of variable inputs is applied. Thus our measure of capacity utilization (CU) as defined, can be greater than, equal to, or less than unity. This is in contrast to most published measures, which are typically less than unity.

There are two concepts of price for a quasi-fixed input in the temporary equilibrium framework: the market or ex ante price (P_i) and the shadow price (Z_i). Assume there is a single quasi-fixed input, capital (K). Shortrun equilibrium is determined by the equality of price (P) with shortrun marginal cost (SRMC). When $Y > Y^*$, the capital stock earns a quasi-rent (Z_K) which exceeds the rent (P_K) earned in other uses. In figure 2, $(Z_K - P_K)K$ corresponds to the area PABC. Berndt and Fuss (1986) show that when $Y \neq Y^*$,

$$(5) \quad P \frac{\partial Y}{\partial K} = Z_K \neq P_K.$$

The preceding quantity or primal CU measure captures the difference between shortrun and longrun equilibrium in a scalar measure based on output. Most capacity utilization measures have been of this type. However, dual-cost measures of capacity utilization are also possible.

One possible dual-cost capacity utilization measure is $C(Y)/C(Y^*)$ where C is total cost. Another possible measure which involves only Y is $C^*(Y)/C(Y)$, where C^* is total shadow cost. Total shadow cost is simply total cost, with the quasi-fixed inputs evaluated at their shadow prices rather than market prices.

In fact, both dual-cost capacity utilization measures are equivalent (Morrison, 1985). Thus the dual-cost measure that we employ in this report is the relatively easy to measure

$$(6) \quad CU^* = \frac{C^*}{C}.$$

For example, when only one quasi-fixed input, capital (K), is used

$$(7) \quad CU^* = \frac{C^*}{C} = \frac{C + (Z_K - P_K) \cdot K}{C}.$$

The primal measure (CU) and the dual measure (CU^*) will both move in the same direction. When $Y > Y^*$, there is a shortage of capital, $Z_K > P_K$, and $C^* > C$. That is, $CU > 1$ implies $CU^* > 1$. Conversely, when $Y < Y^*$, there is an excess of capital, $Z_K < P_K$, and $C^* < C$. That is, $CU < 1$ implies $CU^* < 1$. Finally, when $Y = Y^*$, we are in longrun equilibrium, with $Z_K = P_K$ and $CU = CU^* = 1$.

Traditional productivity measures usually assume that all inputs can be instantaneously adjusted. That is, the shortrun fixity of certain inputs is ignored. Assume a CRTS production function with Hicks-neutral technological progress

$$(8) \quad Y(t) = A(t) F[v(t)].$$

The traditional measure of multifactor productivity growth, assuming all inputs are variable, is

$$(9) \quad \frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \sum_i s_i \frac{\dot{v}_i}{v_i}$$

where s_i is the cost share of input i , and variables with a dot are time derivatives.

Berndt and Fuss (1986), Morrison (1986), and Slade (1986) show that when there are quasi-fixed inputs, the multifactor productivity growth rate should be measured by

$$(10) \quad \frac{\dot{A}^*}{A^*} = \frac{\dot{Y}}{Y} - \sum_j s_{vj} \frac{\dot{v}_j}{v_j} - \sum_i s_{xi} \frac{\dot{X}_i}{X_i}$$

where the weights are $s_{vj} = \frac{w_j v_j}{PY}$ and $s_{xi} = \frac{Z_{xi} X_i}{PY}$

with $PY = \sum_j w_j v_j + \sum_i Z_{xi} X_i$

and Z_{xi} is the shadow price of quasi-fixed input i .

We can consider the effects of variations in capacity utilization on multifactor productivity by valuing quasi-fixed inputs at their shortrun shadow prices rather than their market prices.

However, the Z_{xi} 's are usually unobserved. For the case of one quasi-fixed input (K), we have

$$(11) \quad PY = \sum w_j v_j + Z_K K$$

from which one can estimate Z_K from

$$(12) \quad Z_K = \frac{PY - \sum w_j v_j}{K}.$$

However, this method will not work when we have more than one quasi-fixed input. Alternatively, we can apply a parametric approach permitting the estimation of distinct shadow prices, as shown in the next section.

Morrison (1986) argued that we can adjust productivity growth for variations in capacity utilization simply by dividing the traditional productivity measure by either capacity utilization measure, CU or CU^* :

$$(13) \quad \frac{\dot{A}^*}{A^*} = \frac{\dot{A}/A}{CU}$$

or

$$(14) \quad \frac{\dot{A}^*}{A^*} = \frac{\dot{A}/A}{CU^*}.$$

That is, Morrison argued that when CU or CU^* is less than (greater than) unity, true multifactor productivity growth is greater than (less than) traditional measures of productivity growth.

However, Morrison's argument, represented by equations 13 and 14, is based on an erroneous analysis, which she recognizes in later research (Morrison, 1989). There is no necessary relation between which side of unity CU or CU^* lies and the magnitude of \dot{A}/A^* compared with \dot{A}/A . It is the change in capacity utilization rather than the absolute value of capacity utilization which distorts true productivity growth (see Hauver and Yee, 1992 for additional discussion).

We can give a simple example to illustrate that equations 13 and 14 are not generally valid. In figure 3, let the level of output in the first period be Y_1 . Since $Y_1 < Y_1^*$, $CU < 1$. Let the level of output in the second period be Y_2^* . Suppose true multifactor productivity increases from the first period to the second period, as illustrated by a shift in shortrun average total cost from $SRAC_1$ to $SRAC_2$. True productivity growth is given by the movement from point B to point C. According to equation 13, $\dot{A}/A^* > \dot{A}/A$. But if only data points A and C were observed, multifactor productivity growth is greater than true productivity growth, resulting in a contradiction.

Empirical Model

To illustrate the model empirically, one must specify a functional form for G . Assume there are two variable inputs, hired labor (L) and purchased inputs (M), and two quasi-fixed inputs, capital and land (K), and self-employed labor (S). We also assume that output in period t is produced by quasi-fixed inputs in place at the beginning of the period. Quasi-fixed inputs introduced in period t are not used to produce output in period t . The functional form we choose for G is the quadratic normalized restricted cost function with longrun constant returns to scale imposed:

$$(15) \quad G = L + p_M M = Y \cdot (\alpha_0 + \alpha_M p_M + \alpha_t t + \frac{1}{2} \beta_{MM} p_M^2 + \beta_{Mt} p_M t) + \alpha_K K + \alpha_S S + \frac{1}{2} (\beta_{KK} \frac{K^2}{Y} + \beta_{SS} \frac{S^2}{Y}) + \beta_{MK} p_M K + \beta_{MS} p_M S + \beta_{Kt} K t + \beta_{St} S t.$$

All prices are normalized by the price of hired labor (that is, $p_M = P_M/P_L$).

Using equation 2, we obtain the shortrun purchased inputs demand equation as

$$(16) \quad M = Y \cdot (\alpha_M + \beta_{MM} p_M + \beta_{Mt} t) + \beta_{MK} K + \beta_{MS} S.$$

Furthermore, since $G = L + p_M M$, the hired labor demand equation can be obtained as $L = G - p_M M$. Using equations 15 and 16, we obtain

$$(17) \quad L = Y \cdot (\alpha_0 + \alpha_t t - \frac{1}{2} \beta_{MM} p_M^2) + \alpha_K K + \alpha_S S + \beta_{Kt} K t + \beta_{St} S t + \frac{1}{2} (\beta_{KK} \frac{K^2}{Y} + \beta_{SS} \frac{S^2}{Y}).$$

In addition to the two variable input demand equations, we can also obtain an estimating equation by employing the shadow value relationship (equation 3). Under longrun CRTS, the returns to the quasi-fixed inputs is the residual after payments to the variable inputs have been made. With more than one quasi-fixed input, however, the individual shadow prices are not well defined.

Yet, it is possible to estimate the model using the sum of the shadow values as a single dependent variable. In this case, one can calculate

$$(18) \quad R_{net} \equiv (P \cdot Y - G) = \sum_i Z_i X_i$$

as the dependent variable, and using equation 3

$$(19) \quad \sum_i Z_i X_i = - \sum_i \frac{\partial G}{\partial X_i} X_i$$

as the right-hand-side of the equation. Using the restricted cost function (equation 15), we obtain as an estimating equation

$$(20) \quad R_{net} = - (\alpha_K + \beta_{KK} \frac{K}{Y} + \beta_{MK} P_M + \beta_{Kt} t) \cdot K \\ - (\alpha_S + \beta_{SS} \frac{S}{Y} + \beta_{MS} P_M + \beta_{St} t) \cdot S.$$

In summary, four equations are to be estimated as a system of equations: the restricted cost function (equation 15), the two variable input demand equations 16 and 17, and the shadow value relationship (equation 20). We append an additive disturbance term to each of the four equations, representing random errors in cost minimization, and specify that the four-by-one disturbance vector is independently and identically multivariate, distributed normally with mean vector zero and nonsingular covariance matrix.

An alternative specification can be obtained by substituting a price equation for the shadow value equation 20. In actual empirical estimation (discussed later), the alternative specification yielded results as satisfactory as models with the shadow value relationship. Moreover, the alternative model's results strongly corroborated the findings of the original model, using equation 20. The price equation has the following form:

$$(21) \quad P = \frac{\partial G}{\partial Y} = \alpha_0 + \alpha_M P_M + \alpha_t t + \frac{1}{2} \beta_{MM} P_M^2 + \beta_{Mt} P_M t - \frac{1}{2} \beta_{KK} \frac{K^2}{Y^2} - \frac{1}{2} \beta_{SS} \frac{S^2}{Y^2}.$$

Using the estimated parameters, we can solve for the level of capacity output Y^* . Since G represents minimum possible variable costs, shortrun total cost is $SRTC = G + p_K K + p_S S$, where p_K and p_S are one-period market rental prices (normalized by P_L). To determine Y^* , we differentiate shortrun average total cost with respect to Y and solve for that level of Y which minimizes $SRAC$. Using the form equation 15 for G , we obtain

$$(22) \quad Y^* = \frac{-(\beta_{KK} K^2 + \beta_{SS} S^2)}{(\alpha_K K + \alpha_S S + \beta_{MK} P_M K + \beta_{MS} P_M S + \beta_{Kt} K t + \beta_{St} S t + p_K K + p_S S)}$$

from which we can obtain $CU = Y/Y^*$. Equation 22 can also be obtained by using the longrun equilibrium conditions, $Z_K = P_K$ and $Z_S = P_S$. Alternatively, we can calculate $CU^* = C^*/C$ where $\sum Z_i X_i$ is given by the right-hand-side of equation 20.

Database

The quantity and price data used to estimate the model were taken from Ball (1985) but revised and extended through 1987 (table 1). Tornqvist quantity and price indexes were developed under an assumption of constant returns to scale. Ball identified six categories of agricultural outputs: dairy, livestock and livestock products excluding dairy, feed and food grains, other field crops, vegetables and melons, and fruits and nut trees. For the present study, these have been aggregated into livestock product and crop output variables, as well as a single farm output variable. Output indexes measure quantities marketed, including unredeemed Commodity Credit Corporation loans, changes in farmer-owned inventories, and quantities consumed by farm households.

Inputs include three broad categories, specifically labor, capital, and intermediate or purchased inputs. Ball used labor input data originally developed by Gollop and Jorgenson (1980), which measured wage rates and hours worked by characteristics of the individual worker. Labor input data were decomposed into cells cross-classified by 2 sexes, 8 age groups, 5 educational groups, 2 employment classes, and 10 occupational groups (two of which were relevant for agriculture). The value of labor services equaled the value of labor payments plus the imputed value of unpaid family and self-employed labor. Imputed wage

rates were set equal to the wage rates of hired labor with the same individual characteristics (for example, educational level and age). The original Gollop and Jorgenson time series has been substantially revised and expanded through 1987. Tornqvist quantity and price indexes of hired and self-employed labor (including unpaid family labor) are listed in table 1.

Capital input data were derived from information about investment and outlay on capital services. Ball used a perpetual inventory method to estimate the level of capital stock for 12 assets, grouped broadly into durable equipment (automobiles, trucks, tractors, and other farm machinery), real property (farmland and service structures), and farm-produced durables (beef cows, dairy cows, stocks of bulls, sheep, breeding hogs, and farm inventories). This study used a single Tornqvist index of capital, a weighted aggregate of Ball's 12 assets, which includes farm machinery and equipment, land, and breeding livestock. In addition, disaggregated capital measures were developed and used in some estimations. In these model specifications, capital was disaggregated into durable equipment and machinery, farm-produced durables, and farm real estate.

The dual to the perpetual inventory method provided the theoretical framework for measuring the price of capital services in Ball's original work. He used data on property compensation, the acquisition price of capital, depreciation, and property taxes to derive rental prices and imputed rates of return on capital. The rental price of capital was defined as the sum of the nominal returns to capital and depreciation, less capital gains, and plus property taxes. This relationship stems from viewing the price of acquisition as the discounted value of future rentals.

The use of a residual approach to derive capital price was inappropriate for the present study, since the conceptually correct measure was the market rather than shadow price. We therefore used market interest rates to derive market prices of capital inputs. Prior to 1978, we used the Production Credit Association average interest rate paid on outstanding loans. For 1978 and later years, we used the Federal Reserve survey estimates of the rate on loans not secured by real estate to farmers. Tornqvist price and quantity indexes of capital are listed in table 1.

Intermediate or purchased inputs include energy, agricultural chemicals, feed and seed, and miscellaneous (machine hire and custom work, transportation, cotton ginning, and veterinary services). Table 1 provides Tornqvist price and quantity indexes for the purchased inputs aggregate. In addition, separate Tornqvist price and quantity indexes for energy and nonenergy material purchases are also listed in table 1.

Empirical Estimation and Interpretation

Full information maximum likelihood (FIML) econometric techniques were applied to the estimation of our quadratic, four-equation model for the period 1949-87. The complete model included equation 15 (variable costs), equation 16 (purchased input demand), equation 17 (hired labor demand), and equation 20 (shadow values of quasi-fixed inputs). Shadow prices for the two quasi-fixed inputs, capital and self-employed labor, are given in equation 20.

Estimation required the use of FIML for three reasons. First, cross-equation correlation of error terms is possible. Second, the four-equation model imposes cross-equation restrictions on the values of the coefficients. Specifically, the estimated values of parameters must be the same for all equations. Finally, the model is simultaneous when the current levels of capital and self-employed labor enter as independent variables.

Capital and self-employed labor are assumed to be lagged one period. Lagged measures of quasi-fixed inputs are theoretically preferable, since it is reasonable to assume some delay before new capital investment or self-employed labor become productive. Moreover, lagged stocks are econometrically desirable, since possible endogeneity of the quasi-fixed stock variables is no longer a factor. Estimation results of models using current stocks did not differ greatly from those using lagged stocks but had lower t-statistics.

If stock variables are lagged, the model is no longer simultaneous since all right-hand-side variables become exogenous. The use of FIML econometric techniques is still appropriate, since error terms are correlated across equations and cross-equation restrictions are imposed on coefficient values.

Alternative specifications of the basic quadratic, four-equation model and different measures of the key variables were used in econometric estimation in order to increase the robustness of the results. We estimated six broad categories of alternative model specifications, including disaggregated input models, multioutput models, stock interaction models, price equation models, translog models, and dynamic models. (See appendix for a complete discussion of these models.)

In addition, we used alternative measures of the key variables to test the robustness of our results. In the basic estimation model, variable inputs are measured in absolute terms. However, we also estimated models where variable inputs are measured in ratio to output. In theory, these estimations should yield the same results, though actual empirical estimates may differ slightly.

The empirical analysis of the effect of shifts in factor use on measured productivity proceeded in five steps. First, a Tornqvist index of multifactor productivity was developed, under the assumption that all factors were variable. The unadjusted productivity index (UPI) served as a basis of comparison. Second, the four-equation model was estimated to derive parameter estimates. Third, these parameter estimates were, in turn, used to estimate two capacity utilization indexes. These capacity utilization measures were a primal-capacity utilization index (CU) based on quantity, and a dual-capacity utilization index (CU*) based on cost. Fourth, a second Tornqvist index of multifactor productivity, an adjusted productivity index (API), was derived, under the assumption that some inputs are quasi fixed. Fifth, the unadjusted and adjusted productivity indexes were compared.

A Tornqvist index of multifactor productivity growth was derived from equation 9, using time series data listed in table 1. Equation 9 provided annual productivity growth rates, which were then converted into a multifactor productivity index (1982 = 100). This index treated all inputs as variable and can therefore be designated the UPI. The UPI index for the period 1949-87 is presented in table 2.

In the second stage of empirical analysis, FIML was applied to the four-equation model. The resulting parameter estimates, reported in table 3, became the basis for all subsequent empirical analysis, including the calculation of primal- and dual-capacity utilization measures and the derivation of shadow prices for quasi-fixed inputs.

Capacity utilization measures may be either primal (CU), derived from a ratio of quantities (equation 4), or dual (CU*), based on a ratio of costs (equation 6). In order to obtain the primal CU measure, we can use the previously estimated model parameters to compute capacity output, Y^* , from equation 22. The primal CU measure can then be derived simply from the ratio of actual to capacity output (Y/Y^*).

Derivation of the dual CU* measure required first the calculation of C^* , or the sum of factor costs, where quasi-fixed inputs are evaluated at their shadow prices. Distinct shadow prices for capital and self-employed labor are obtained for each year using equation 20. Annual estimates of C^* are then derived from the weighted sum of all four factors. Variable factors, hired labor, and purchased inputs, are evaluated at their market prices, and quasi-fixed inputs are weighted by their shadow prices. In contrast, total costs, C , are obtained for each year by applying market prices to all four inputs. The dual CU* measure is then derived from the ratio of total shadow costs to total costs (C^*/C). Using these procedures, we obtained primal- and dual-capacity utilization measures for the period 1949-87, as reported in table 4.

The capacity utilization API was obtained by applying equation 10, where shadow prices were used in place of market prices for quasi-fixed inputs. Adjusted growth rates were then converted into productivity indexes (1982 = 100). Table 2 presents adjusted and unadjusted growth rates, together with their respective indexes for the 1949-87 period.

Parameter Estimates

Parameter estimates for the quadratic, four-equation model together with t-statistics are displayed in table 3. Relevant single equation statistics, such as R^2 and Durbin-Watson statistics, are presented in table 3.

Nine out of 13 parameter estimates were statistically significant, judging by their t-statistics and had the correct sign. All R^2 s and corrected R^2 s were positive. The corrected R^2 s were high for the variable cost and material purchases equations, but somewhat lower for the hired labor and shadow value equations. Measured R^2 s are dependent on the type of data used, and the lower corrected R^2 for hired labor and shadow value relationships may reflect diverse data sources and the number of parameters estimated. The Durbin-Watson statistic was quite satisfactory for the variable cost, material purchases, and hired labor equations, indicating no autocorrelation. The lower Durbin-Watson statistic for the shadow value equation was in the range of indeterminacy. No correlation between the coefficients was evident except for the constant term.

Capacity Utilization Measures

Parameter estimates were used to derive primal- and dual-capacity utilization measures, shown in table 4 for 1949-87. No value could be computed for 1948, due to the use of lagged capital stocks and self-employed labor in the estimation. Figure 4 displays the relationship between CU and CU^* during this period. Figure 5 shows the value of CU^* over time alone.

Several observations are noteworthy. First, prior to 1981, most capacity utilization measures, whether primal or dual, are above but close to 1. These findings are consistent with similar results reported for the manufacturing sector. Berndt, Morrison, and Watkins (1981), using a comparable approach, estimated capacity utilization in U.S. manufacturing for 1952-71. Their capacity utilization measures were all greater than 1, with the exception of 1 year. Furthermore, their capacity utilization estimates were all very close to 1. By contrast, the well-known Wharton and Federal Reserve Board indexes of capacity utilization in U.S. manufacturing for 1952-71 were always less than 1.

Morrison (1986) estimated capacity utilization in U.S. manufacturing for 1949-79. Her capacity utilization measures were greater than 1 for almost all years and always very close to 1.

The observation that capacity utilization for the 1949-80 period is usually above 1 requires an explanation. Government subsidies to farm production may provide one possible answer but do not explain a similar finding for the manufacturing sector. The manufacturing sector is imperfectly competitive. Economic theory suggests that a firm in an imperfectly competitive industry will produce a level of output less than the capacity output.

Second, both primal- and dual-capacity utilization measures experience sharp declines after 1978, thereby reducing average capacity utilization over the entire 1949-87 estimation period. Dual-capacity utilization averaged 1.025 for 1949-80, but fell to 0.735 for 1981-87, resulting in an overall average 0.973 for 1949-87. This pattern is even more striking for primal-capacity utilization. Primal-capacity utilization averaged 1.224 for 1949-80, but became negative in the 1981-87 period (-3.167), resulting in an average 0.436 for 1949-87. Although negative capacity utilization is conceptually unacceptable, primal capacity utilization measures display the same general pattern as dual measures: values above 1 prior to 1981 and values less than 1 thereafter. Even their cyclic patterns through time are remarkably similar, as can be seen by comparing figures 4 and 5.

Low-capacity utilization in the 1980's reflected the economic crisis affecting the farm sector during those years. Declining exports, falling farm product prices, and collapsing land values undermined the financial solvency of many farms. Production fell and farm operators curtailed purchases of farm inputs, notably capital.

Third, primal-capacity utilization measures proved to be far more volatile than dual measures and experienced a greater range of values. In fact, primal capacity utilization became negative in the 1980's.

Since dual-capacity measures were more stable and remained positive throughout the estimation period, they provided a better basis for subsequent analysis.

Fourth, capacity utilization measures varied systematically over time, rising steadily until the late 1970's, before declining sharply in the 1980's. When examined in 5-year intervals, dual-capacity utilization rose from 0.944 (1949-53) to a peak of 1.121 (1974-78), and then declined to 0.922 for 1979-83, and 0.686 for 1984-87.

Fifth, capacity utilization appears to follow something of a cyclic pattern of uncertain origin. Despite its greater volatility, primal-capacity utilization measures showed the same cyclic patterns as dual measures. Dual-capacity utilization revealed five distinct peaks, interspersed with declines: 0.990 (1949-51), 0.977 (1954-58), 1.028 (1961-69), 1.123 (1971-73), and 1.190 (1977-79). Possible explanations for this pattern include shifts in government policy affecting the farm sector, changes in export demand, and weather conditions. These issues will be explored later in this report.

Ratios of Shadow Price to Market Price

The computation of shadow prices for capital and self-employed labor was an important step in the derivation of dual-capacity utilization measures. We constructed ratios of shadow prices to market prices for capital and self-employed labor for the 1949-87 period, revealing important relationships between these inputs. First, the value of the ratio for capital (fig. 6) was well above 1 throughout the 1949-80 period but declined sharply in the 1980's. The capital shadow price ratio averaged 1.402 during 1949-80 but only 0.586 for 1981-87. When examined in 5-year intervals, the capital shadow price ratio oscillated, but showed no clear trend until the mid-1960's when the ratio began a steady upward movement which lasted throughout the 1970's, only to collapse in the 1980's. The capital shadow price ratio fell from 1.253 (1949-53) to 1.160 (1959-63), before rising steadily thereafter to its historic peak of 1.823 during the 1974-78 period. The ratio fell to an average 0.515 for the most recent period (1984-87). The capital shadow price ratio achieved its highest point in 1978 (2.864) and its lowest level in 1986 (0.474). The excess of shadow price over market price experienced prior to 1981 indicated a capital shortage from 1949 to 1980, but the deficiency of shadow prices relative to market prices after 1980 indicated a capital surplus.

Second, the ratio of shadow price to market price for self-employed labor (fig. 7) was well below 1 throughout the 1949-87 period, indicating a labor surplus. The surplus worsened consistently after the mid-1970's, but the trend is complex with many short-term variations. For the entire 1949-87 estimation period, the shadow price ratio for self-employed labor averaged 0.634. When examined in 5-year intervals, the ratio oscillated but declined moderately until the mid-1970's, falling from 0.713 (1949-53) to 0.622 (1974-78). More recently, the shadow price ratio fell more precipitously to 0.434 for 1984-87. The ratio attained its lowest value for the entire estimation period in 1987 (0.373).

Third, the capital shadow price ratio moves with shifts in capacity utilization, as theory suggests. A rise in the shadow price of capital relative to its market price would encourage production beyond capacity output. However, no such match was evident between the shadow price ratio for self-employed labor and capacity utilization. Movements in the capital shadow price ratio dominated, since capital represented a far greater share of total cost compared with self-employed labor.

Adjusted and Unadjusted Productivity Indexes

A capacity utilization adjusted productivity growth rate can be computed directly from equation 10 where the shadow prices of quasi-fixed inputs are used in place of market prices. The adjusted productivity growth rates can then be converted into index numbers (API), with 1982 as the base year. API's consider variations in the use of quasi-fixed inputs by using shadow prices in place of market prices. The unadjusted productivity index (UPI) and the API are displayed in figure 8. Table 2 presents unadjusted and adjusted productivity growth rates and the resulting index numbers for the 1949-87 period.

Over the entire 1949-87 estimation period, the average adjusted and unadjusted productivity growth rates were substantially different. The average growth rate of unadjusted productivity was 2.010 percent each

year for 1949-87. Adjusting for disequilibrium reduced this growth rate by 17.020 percent, to 1.670 percent per year. Disequilibrium systematically exaggerates observed productivity gains over true productivity growth for the entire period, magnifying the cumulative effect as seen in the productivity indexes. However, the two productivity indexes display similar periodic patterns. Adjusting for variation in the use of quasi-fixed inputs does not smooth observed short-term productivity shifts as theory would suggest.

Productivity growth is not uniform over time but appears to follow a cyclic pattern. Four distinct productivity cycles (defined from trough to trough) appear to have occurred between 1949 and 1987. Average unadjusted productivity declined over time but rose substantially in the 1980's: 1.980 percent per year (1950-55), 1.260 percent (1956-70), 1.160 percent (1971-80), and 4.840 percent (1981-87).

Adjusted productivity growth showed similar time patterns. For 1950-55, adjusted productivity growth averaged 1.280 percent per year, but declined to 0.880 percent per annum for 1956-70, before rising somewhat to 0.930 percent per year for 1971-80. For 1981-87, however, adjusted productivity growth averaged 4.740 percent per year.

The quantitative importance of disequilibrium upon observed productivity growth can be derived by taking the difference between the unadjusted productivity growth rate and the adjusted productivity growth rate (fig. 9). Disequilibrium clearly had the greatest effect in earlier years. During 1950-55, disequilibrium averaged 0.700 percent per year, or 35.450 percent of observed unadjusted productivity growth. The relative importance of disequilibrium declined over time, falling to an average 0.380 percent per year, or 30.000 percent of unadjusted growth for 1956-70, 0.240 percent per year (20.400 percent of unadjusted growth) for 1971-80, and 0.100 percent per year (2.140 percent of unadjusted growth) for 1981-87. Over the entire estimation period, disequilibrium averaged 0.340 percent per year and accounted for 17.020 percent of observed unadjusted productivity growth, a substantial distortion. Because the quantitative importance of disequilibrium was greater in the earlier years, the difference between unadjusted and adjusted productivity growth is also greater in the earlier period.

When examined in 5-year intervals, the relationship between unadjusted productivity growth, adjusted productivity growth, and disequilibrium is more complex, but the same general patterns are evident. With some variations, unadjusted productivity growth declined from an average 2.490 percent increase per year for 1949-53, to a -0.090 percent per year decline for 1974-78 but rebounded to 6.670 percent per year for 1984-87. Adjusted productivity growth fell from an average 1.550 percent per year increase for 1949-53 to a 0.490 percent increase per year income for 1964-68, then rose to 2.280 percent per year for 1969-73, declined to 0.160 percent per year for 1974-78, and rose to 6.410 percent per year for 1984-87. Disequilibrium shows a general decline but with variations. Disequilibrium fell from 0.930 percent per year on average for 1949-53, to 0.340 percent per year for 1964-68, rose to 0.430 percent per year for 1969-73, and actually became negative during the 1974-78 period (-0.250 percent per year). Thereafter, disequilibrium rose to 0.360 percent per year for 1979-83 and declined again to 0.260 percent per year for 1984-87. Clearly, the relative importance of disequilibrium varied substantially over time. For 1949-53, disequilibrium represented 37.540 percent of unadjusted productivity growth, but this percentage varied greatly during subsequent periods, ranging from 41.960 percent (1979-83) to 3.890 percent (1984-87). The disequilibrium patterns may be linked to government subsidies and changes in export demand.

The substantial difference between unadjusted and adjusted productivity growth stems from the difference between shadow and market prices for self-employed labor and capital. As noted earlier, the shadow price of capital was consistently above its market price until 1981, particularly in the late 1970's, while the shadow price of self-employed labor was well below its market price, especially after 1973.

Productivity growth rates manifest sharp year-to-year volatility, possibly masking trends over time. In order to remove some of the data noise, we computed 5-year moving average productivity growth rates for both adjusted and unadjusted productivity time series. The results are shown in figure 10. Four patterns are evident. First, by using moving averages, much of the volatility of the data is removed. Second, adjusted productivity growth did decline overall until 1981, but two peaks are evident: in the late 1950's and early 1960's, and late 1960's and early 1970's. Third, both unadjusted and adjusted productivity growth increased substantially in the 1980's. Finally, volatility seemed to increase in the later years.

Other Estimations

We used alternative model specifications and different measures of key variables to conduct over 30 estimations, in addition to that of the basic quadratic, four-equation model. The best results were achieved with price equation models and multioutput models, lending strong support to the findings of the basic model. Estimates of capacity utilization, shadow price ratios, and adjusted productivity growth were nearly identical to our original findings. In addition, models defining variable input demand in absolute terms provided better results than those measuring variable inputs in ratio to output. Disaggregated input models, stock interaction models, translog, and dynamic models were less satisfactory. These estimations are discussed in the appendix.

Causal Factors

The fact that disequilibrium accounts for nearly 17 percent of observed productivity growth during the 1949-87 period calls for some explanation. Two likely causes can be identified. First, net production subsidies from the public sector encourage farm operators to produce beyond the minimum point of their average cost curve. This is consistent with the capacity utilization measures usually being above 1 before 1981. A possibly greater factor is unexpected changes in export demand, particularly since 1970.

The effects of U.S. farm policy on the agricultural sector will vary over time as policies are changed to deal with different political and economic circumstances (U.S. Department of Agriculture 1985, 1988), but some general observations can be made. First, U.S. farm policy provides a substantial production subsidy in the farm sector and has done so consistently since World War II. Second, increased export demand greatly stimulated production in the 1970's, temporarily diminishing the importance of public subsidies in farm income. In the 1980's, collapsing export demand depressed agricultural production, although this effect was offset somewhat by increased public sector subsidies. Third, the increased importance of exports for the farm sector has led to greater volatility of farm prices and incomes.

These observations seem to correspond with the empirical findings reported earlier. Before 1981, capacity utilization was usually above 1, as would be expected when substantial public production subsidies were present. Increased export demand stimulated production as well. Increased volatility of observed productivity growth rates in the 1970's appears to correspond to the increasing importance of exports in the farm sector. Finally, falling exports certainly contributed to the decline in capacity utilization in the 1980's.

Our empirical results can also be compared with Dvoskin (1988). Dvoskin defines excess capacity as the difference between supply and demand at the prevailing price. Although our measure of capacity utilization is fundamentally different in concept and purpose, it is interesting to note that the time pattern of his excess capacity and our capacity utilization measures are quite similar, particularly after 1970, probably reflecting the influence of the same policy variables.

Conclusions

This study builds upon the capacity utilization literature previously completed for the manufacturing sector by applying a similar theoretical framework to the farm sector. Two capacity utilization measures were computed, a primal (CU) and a dual (CU*). Prior to 1981, these measures were usually above 1, but also close to 1, findings which are consistent with those of Berndt, Morrison, and Watkins (1981) and Morrison (1986) for the manufacturing sector. Dual-capacity utilization fell well below 1 in the 1980's. Capacity utilization varied over time, with higher levels in the 1970's than in earlier or later periods.

An analysis of shadow prices for capital and self-employed labor indicated that a capital shortage prevailed for most of the period prior to 1981. In the 1980's, however, capital was in surplus. A self-employed labor surplus existed throughout the entire 1949-87 estimation period.

Disequilibrium accounted for more than 17 percent of observed productivity growth during the 1949-87 period. The observed average growth rate of unadjusted productivity was 2.009 percent per year, but adjusting for disequilibrium reduces this growth rate to 1.668 percent per year. The quantitative importance of disequilibrium was greater in earlier years. However, the unadjusted and adjusted productivity indexes display similar periodic patterns. Adjusting for variation in the use of quasi-fixed inputs does not smooth observed short-term productivity shifts.

Over time, unadjusted and adjusted productivity growth displayed similar patterns. Average unadjusted productivity growth generally fell until the late 1970's but increased sharply in the 1980's. Average annual unadjusted productivity growth declined from 1.908 percent per year for 1950-55 to 1.160 percent per year for 1971-80, but rose on average to 4.840 percent per year during 1981-87. Volatility in growth rates appears to have increased in the latter part of the estimation period.

Adjusted productivity growth averaged 1.280 percent per year from 1950 through 1955, but declined to 0.880 percent per annum for 1956-70, before rising to 0.930 percent per year for 1971-80. For 1981 through 1987, however, adjusted productivity growth averaged 4.740 percent per year, a marked increase.

Two factors appear to account for the significant effect of disequilibrium on observed productivity growth: large net production subsidies from the public sector and unexpected changes in export demand. Agricultural exports increased sharply in the 1970's but fell as dramatically in the 1980's.

The model appears to be well specified. Most parameter estimates are statistically significant. Corrected R^2 and Durbin-Watson statistics are also encouraging. Little autocorrelation was evident, and the model explained a substantial part of the variation in the data. Alternative price equation and multioutput specifications yielded essentially the same results, together with high t-statistics.

Future research should explore the underlying factors accounting for variations in capacity utilization over time, including the role of public sector subsidies and export demand. In addition, productivity growth has not been uniform, suggesting the need for further research into the sources of growth.

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Figure 1
Longrun equilibrium

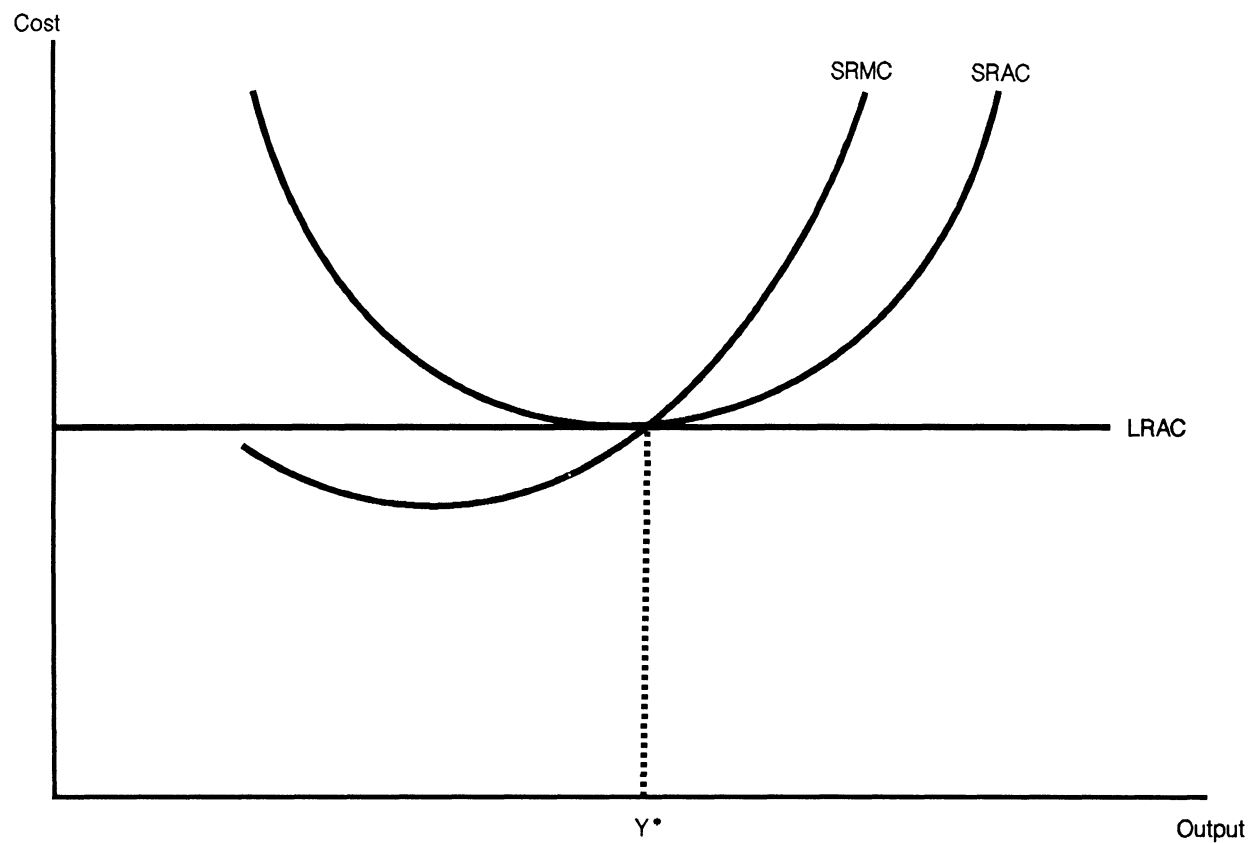


Figure 2
Shortrun equilibrium

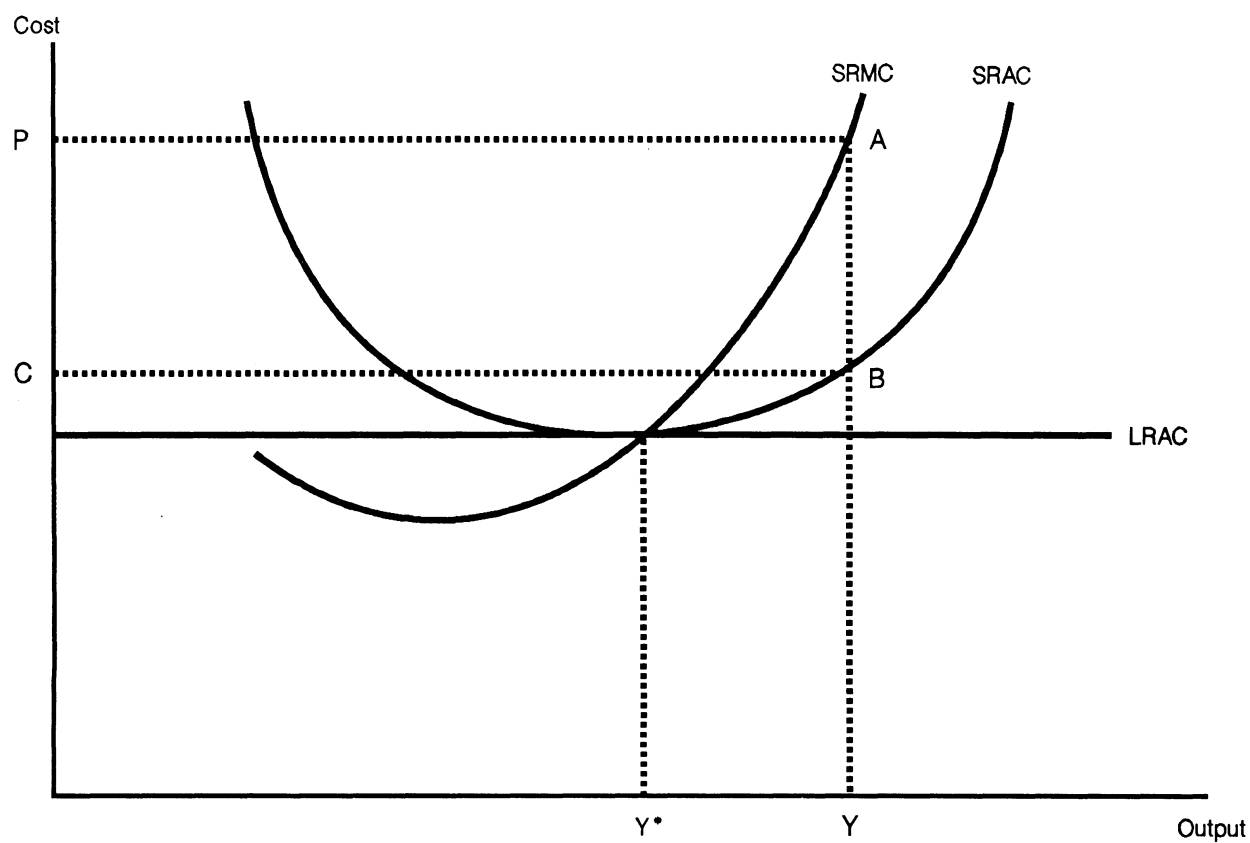


Figure 3

Overstatement of productivity growth

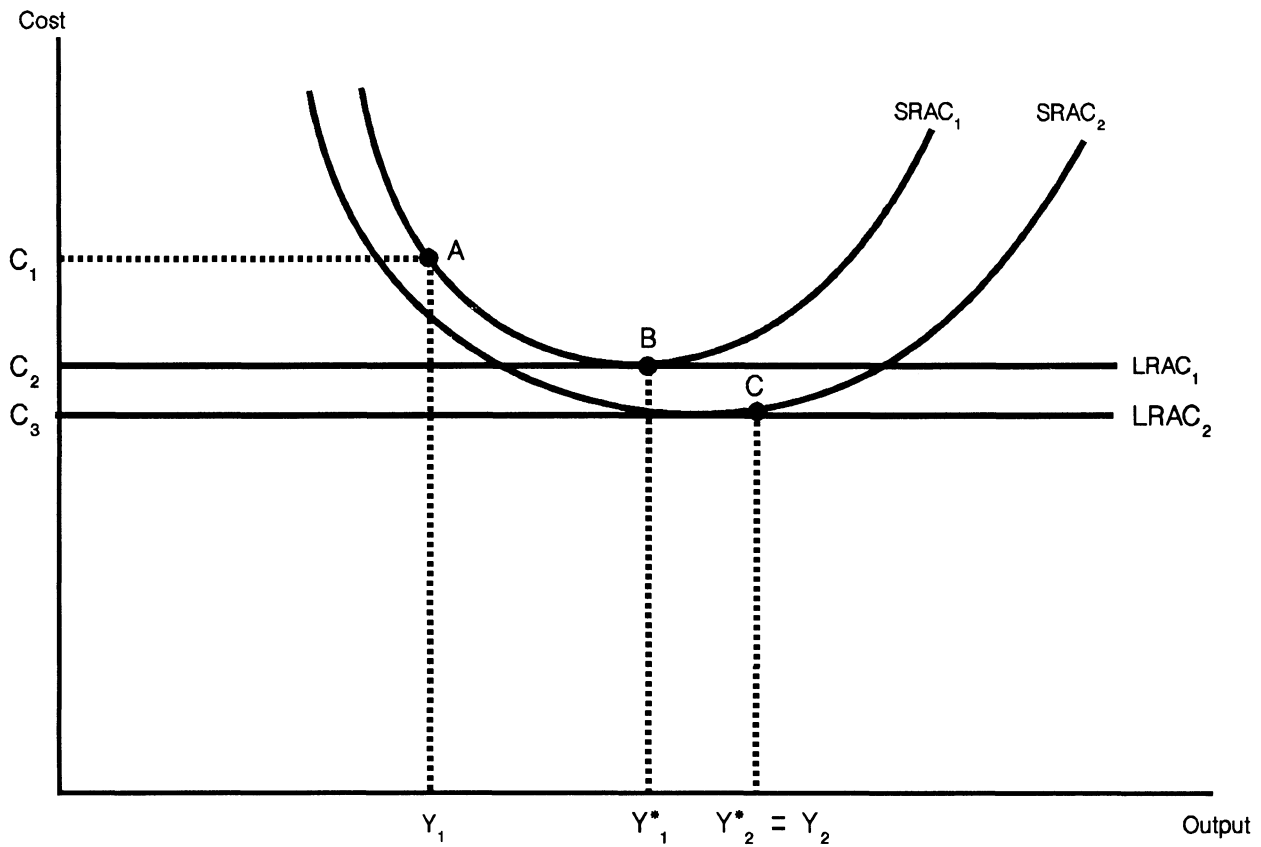


Figure 4

Capacity utilization

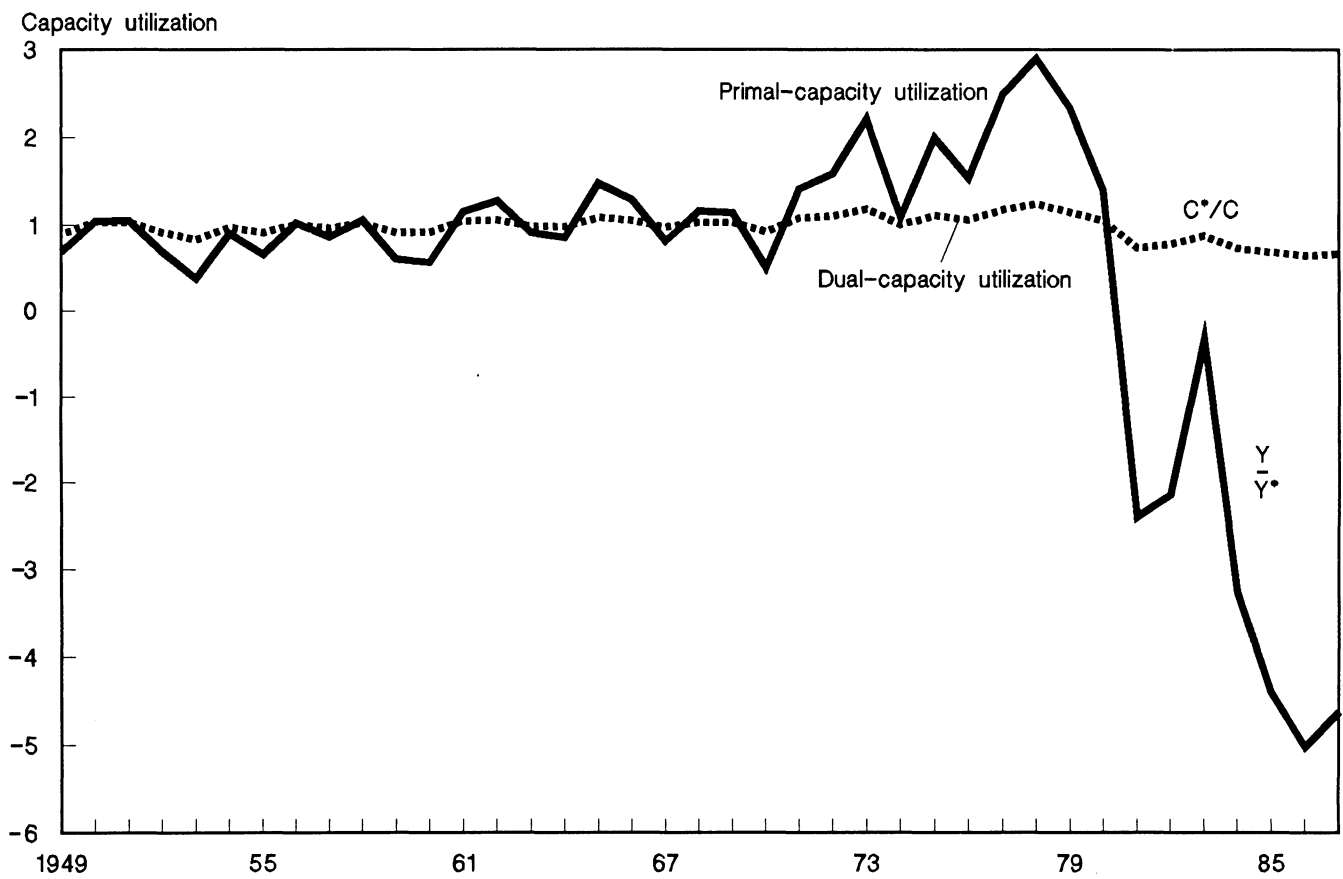


Figure 5
Dual-capacity utilization

Capacity utilization

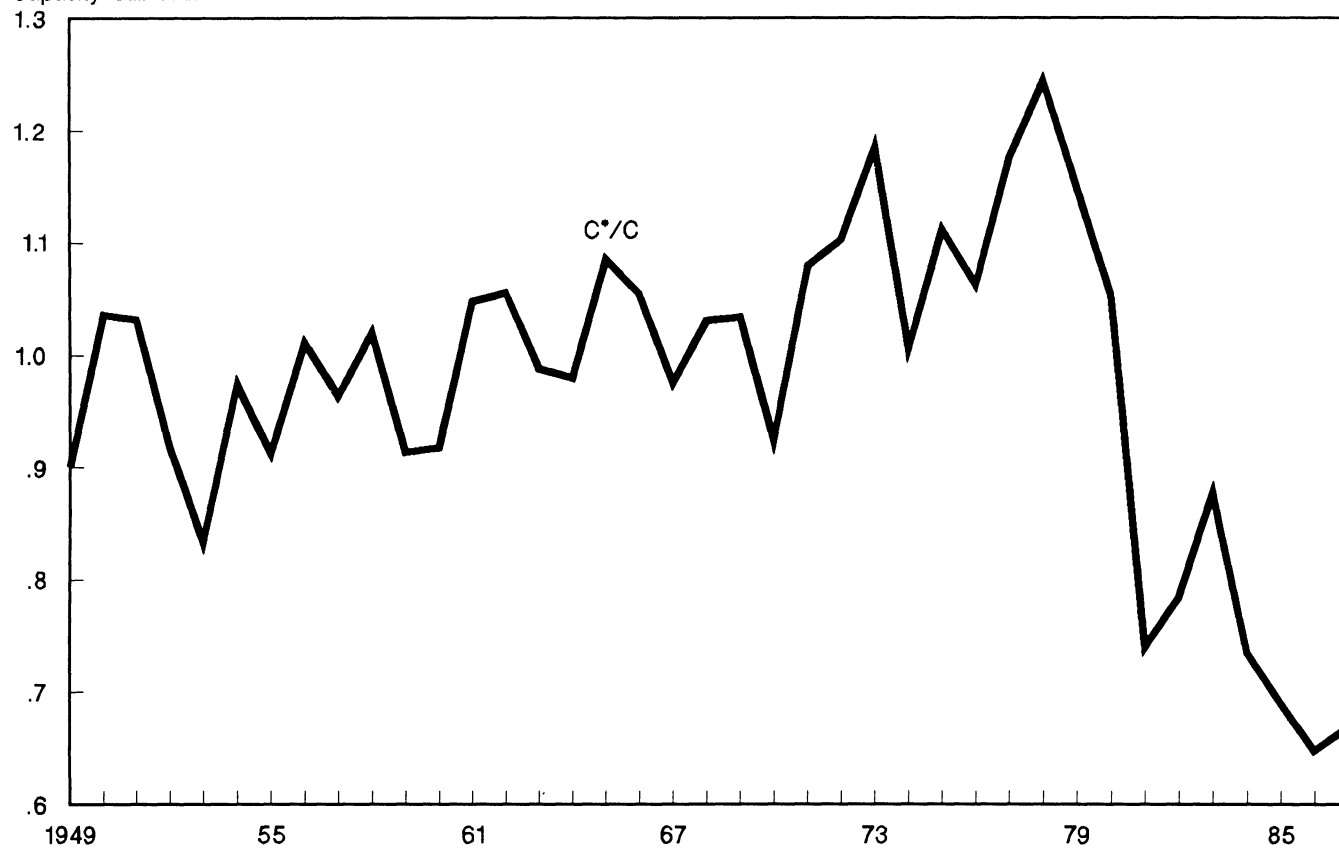


Figure 6
Shadow price-market price ratio for capital

Price ratio

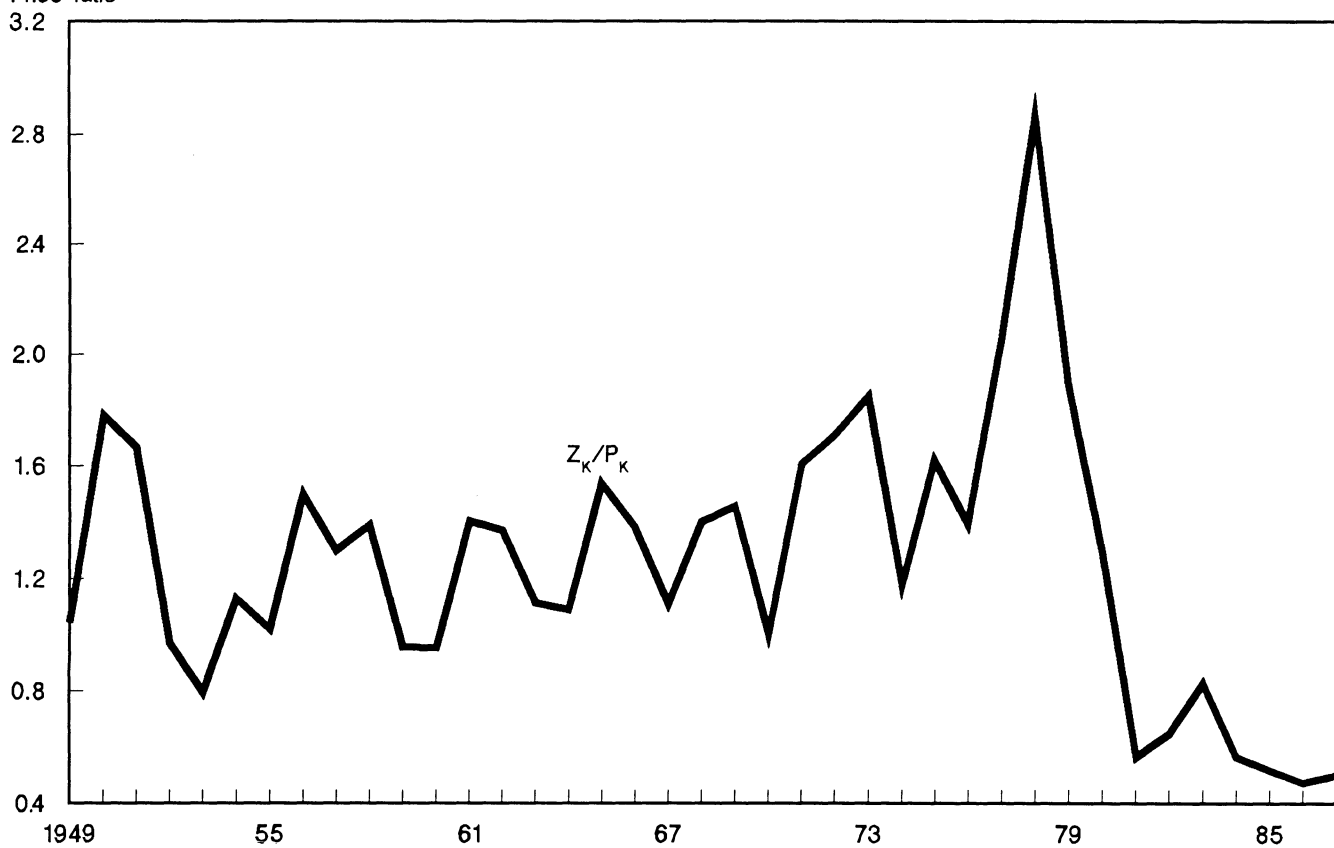


Figure 7

Shadow price-market price ratio for self-employed labor

Price ratio

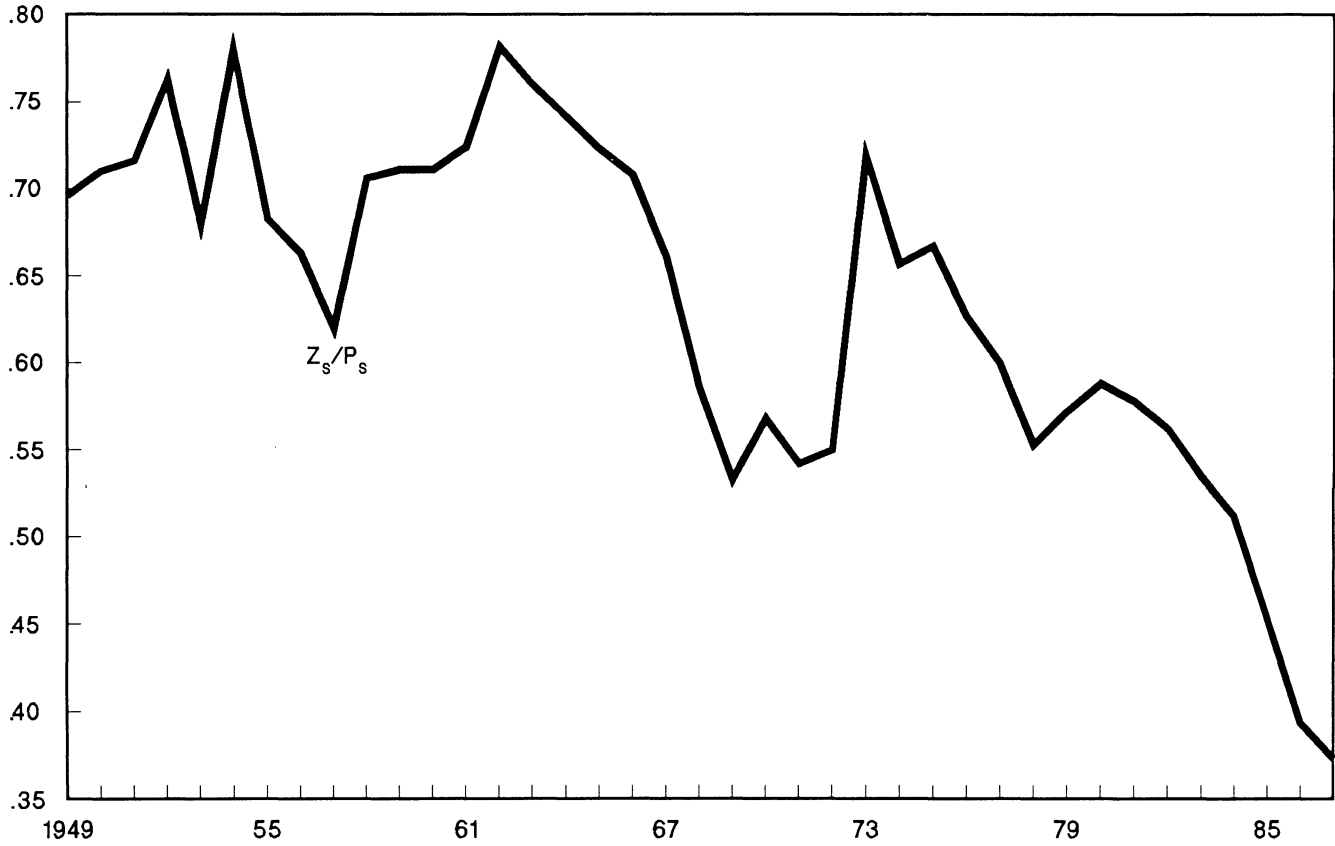


Figure 8

Productivity Indexes

1982 = 100

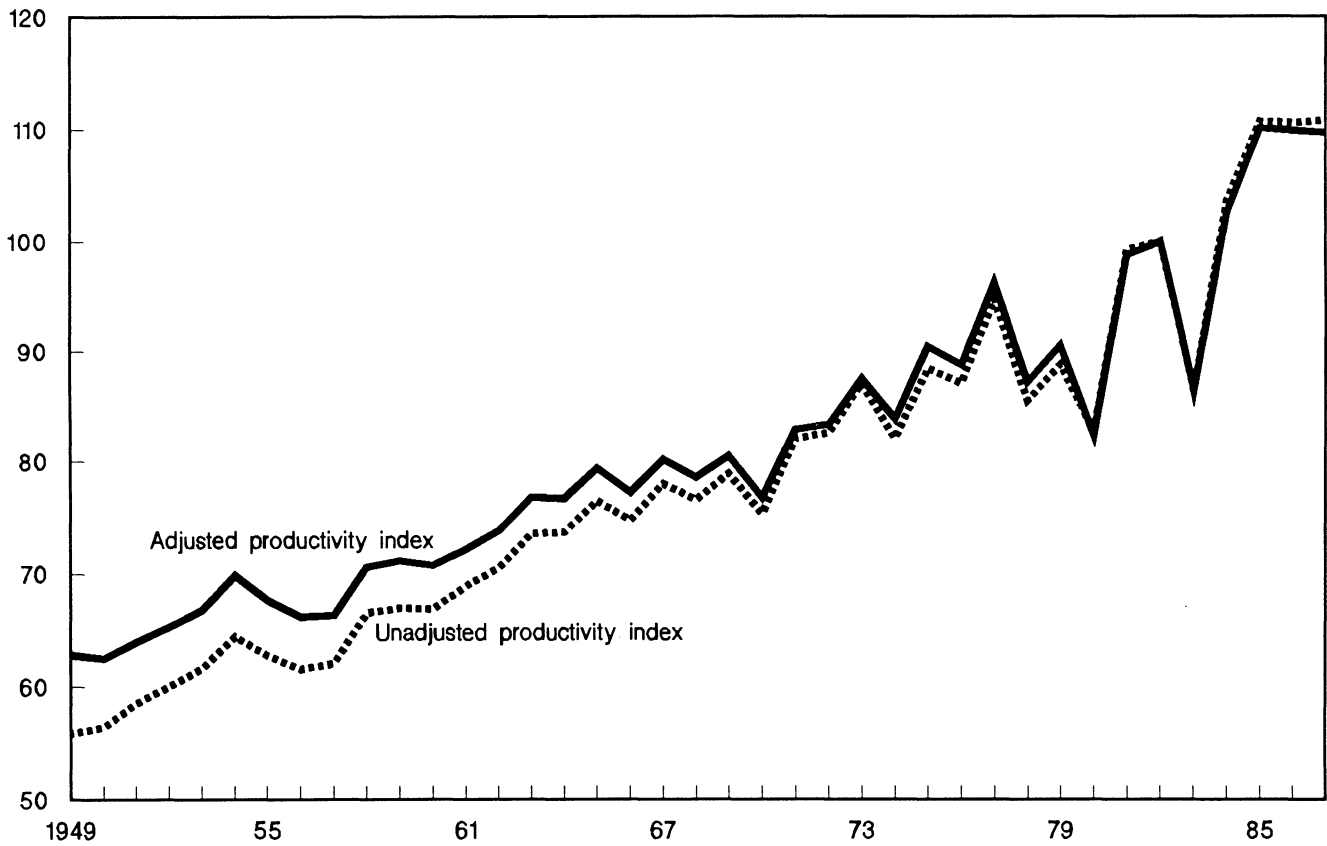


Figure 9

Disequilibrium effect

Growth rates

7%

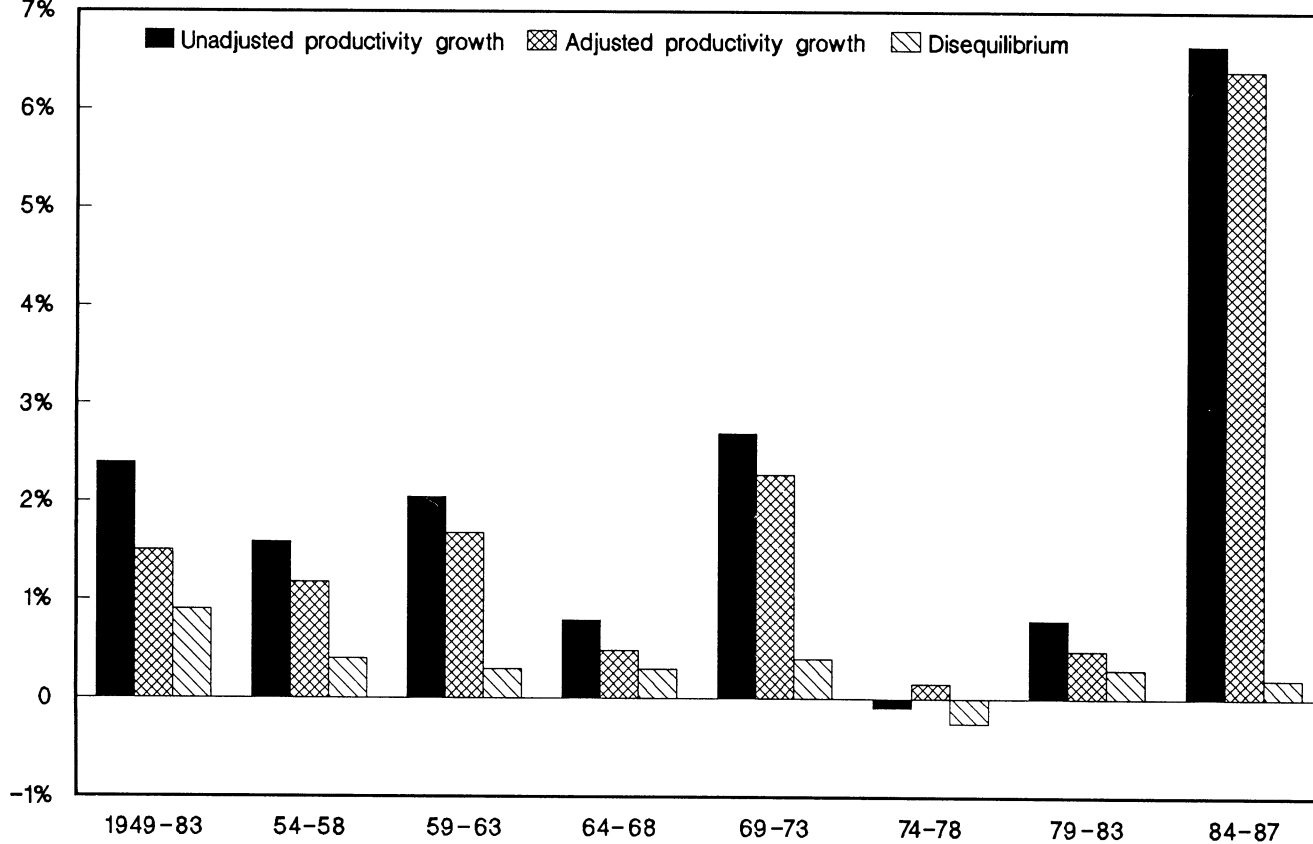


Figure 10

Moving average productivity growth rates

Growth rates

8%

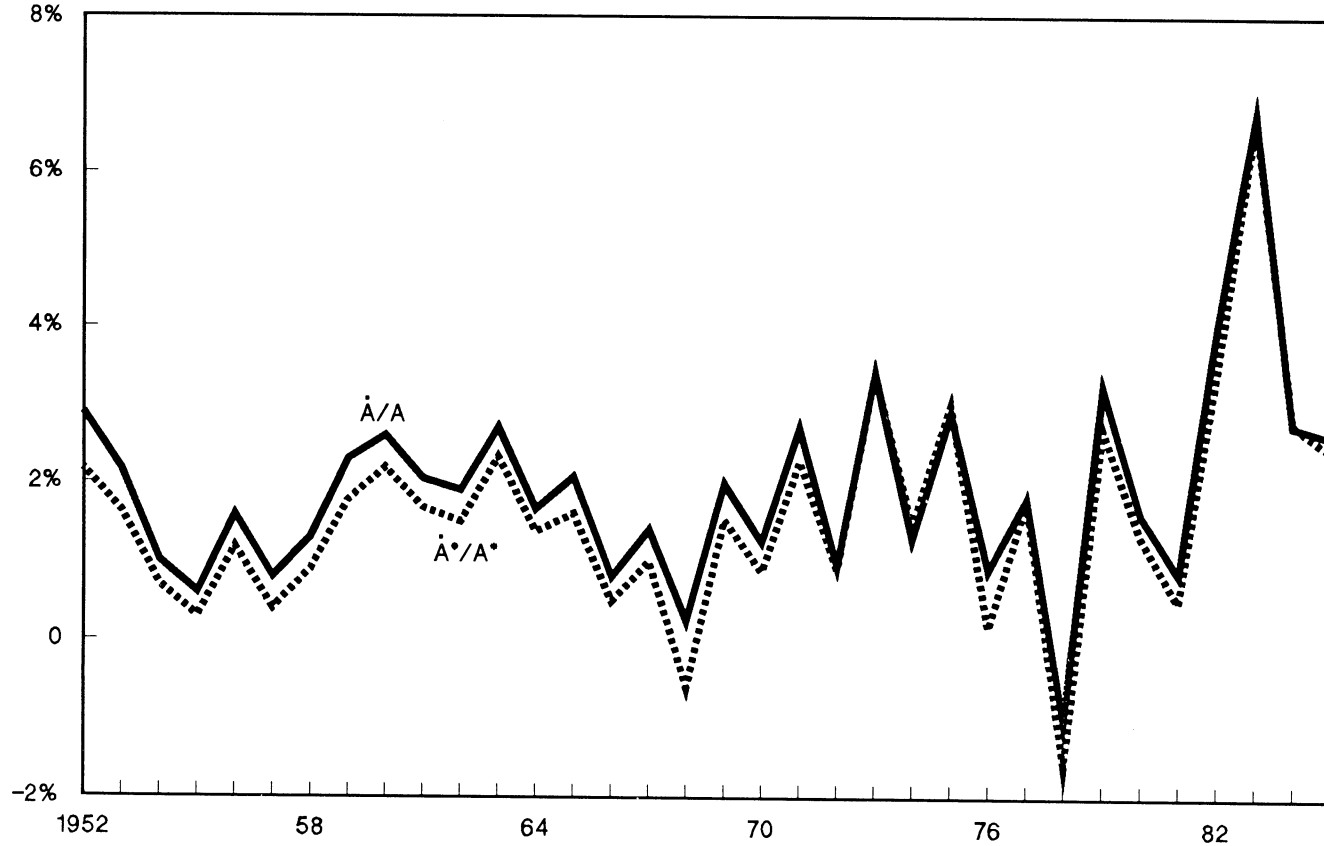


Table 1--Time series data: Tornqvist indexes of prices and quantities

Year	POUT	QOUT	PCROPS	QCROPS	PANIMAL
<u>1982 = 100</u>					
1948	0.49616	65932.3	0.50093	31720.6	0.47580
1949	.43500	63376.0	.45278	27428.6	.40610
1950	.44902	64702.7	.48193	26969.3	.40881
1951	.50191	67982.7	.48486	29248.8	.49493
1952	.47882	70090.5	.49678	30620.8	.44700
1953	.44006	71056.6	.46703	30966.2	.40308
1954	.41955	72947.3	.45980	31276.4	.37367
1955	.40078	74913.9	.44674	32314.2	.35154
1956	.40050	74959.7	.45679	31921.7	.34384
1957	.40871	73897.0	.44019	31333.6	.36921
1958	.43348	77812.1	.44911	34122.2	.40449
1959	.41087	80269.8	.42888	35151.8	.38101
1960	.40492	82639.3	.42547	36856.0	.37338
1961	.41759	84642.7	.45946	36817.7	.36943
1962	.42694	86103.6	.47702	37411.7	.37233
1963	.42102	89549.8	.47864	39585.9	.36101
1964	.41420	89227.3	.48857	37747.3	.34226
1965	.43892	93668.4	.50072	42630.9	.37551
1966	.48446	91348.7	.53976	39545.4	.42439
1967	.45438	97208.3	.50367	43603.5	.40002
1968	.46493	96768.1	.50624	43195.4	.41645
1969	.49116	100048.0	.50307	46235.8	.46545
1970	.52645	96526.8	.56191	41532.3	.48123
1971	.50238	106097.0	.52983	49405.4	.46440
1972	.57631	106264.0	.60031	49414.7	.53905
1973	.79307	110706.0	.83721	54850.4	.73171
1974	.83431	106353.0	.01158	49792.6	.65222
1975	.78547	113132.0	.87235	57994.0	.68929
1976	.78594	113746.0	.85542	56196.8	.70739
1977	.77695	121800.0	.84083	62895.9	.70403
1978	.89622	121815.0	.92018	63373.8	.86511
1979	1.00200	129863.0	.97534	70879.9	1.02785
1980	1.02489	125420.0	1.05722	63053.2	.98600
1981	1.04011	138867.0	1.07575	75542.2	.99761
1982	1.00000	137710.0	1.00000	74904.4	1.00000
1983	1.10930	118111.0	1.25149	54814.6	.96566
1984	1.07288	141150.0	1.12943	77108.3	1.01800
1985	.97758	147280.0	1.00674	81255.7	.95517
1986	.96548	143616.0	.98053	76501.2	.95984
1987	1.01493	142926.0	1.02949	75286.6	1.01038

See notes at end of table.

Continued--

Table 1--Time series data: Tornqvist indexes of prices and quantities--Continued

Year	QANIMAL	PHL	QHL	PSL	QSL
<u>1982 = 100</u>					
1948	35357.5	0.247428	12273.50	0.231837	53132.3
1949	37306.2	.229535	12593.60	.214882	52534.4
1950	39272.7	.228227	12180.90	.211714	49127.9
1951	40287.1	.261344	11181.20	.239739	46520.0
1952	41049.2	.276060	10072.90	.247040	45746.0
1953	41697.0	.284578	8837.45	.250995	42539.5
1954	43418.6	.279535	8101.88	.247934	41918.8
1955	44341.5	.282591	9828.12	.250995	40847.2
1956	44903.8	.296790	9440.61	.249685	40891.1
1957	44444.8	.302845	9025.33	.252602	37662.7
1958	45502.2	.312686	8776.73	.260256	35077.5
1959	46991.8	.328769	8587.75	.268145	35240.8
1960	47622.6	.311650	10252.40	.259913	34218.8
1961	49886.6	.313988	9790.03	.275755	31201.9
1962	50800.5	.309587	9513.18	.280096	30711.5
1963	51951.7	.320256	9855.52	.295713	28224.8
1964	54097.7	.321848	9330.03	.303825	26820.0
1965	52639.9	.332500	9188.57	.319995	26398.5
1966	53983.1	.344107	8271.32	.336691	24940.4
1967	55515.5	.366269	8700.38	.362890	23525.8
1968	55525.3	.395679	8097.46	.392903	23456.1
1969	55601.1	.450486	7363.16	.420655	22355.2
1970	57101.3	.408345	7996.26	.424210	22198.6
1971	58408.5	.428162	7955.77	.461606	20740.2
1972	58578.9	.462813	8360.85	.484839	20785.6
1973	57231.1	.501015	8622.48	.522120	20225.2
1974	58819.0	.579413	9565.66	.601943	19440.5
1975	55521.9	.602129	9220.09	.625440	19272.8
1976	58418.9	.650634	9082.67	.671095	18306.5
1977	59297.7	.715575	9248.22	.735875	17816.7
1978	58787.2	.774216	9593.71	.784272	17905.8
1979	59338.4	.849059	9229.25	.855873	17865.3
1980	62759.4	.933580	8664.15	.920220	17579.8
1981	63324.6	1.002970	8950.11	1.006980	17385.6
1982	62805.2	1.000000	8948.00	1.000000	16616.0
1983	64640.5	1.050220	9701.55	1.027970	16047.5
1984	63211.1	1.093320	9965.59	1.085720	14950.7
1985	65092.3	1.115650	9408.11	1.103480	13740.7
1986	66310.7	1.182190	9040.69	1.165810	13461.2
1987	66859.3	1.222450	9258.32	1.206800	12739.9

See notes at end of table.

Continued--

Table 1--Time series data: Tornqvist indexes of prices and quantities--Continued

Year	PKAP	QKAP	PDE	QDE	PRE
<u>1982 = 100</u>					
1948	0.11418	52906.1	0.08566	9323.3	0.00847
1949	.14506	55492.6	.14401	11090.2	.04690
1950	.08429	60557.3	.21077	12836.6	.04824
1951	.09652	64410.2	.14427	14355.3	.07154
1952	.17262	68467.3	.22181	15584.5	.04911
1953	.19617	71162.1	.24231	16239.0	.04135
1954	.14549	72013.8	.24665	17031.1	.07330
1955	.14730	72918.9	.22064	17283.1	.07152
1956	.09941	76029.6	.20049	17464.8	.04984
1957	.11264	73546.6	.21057	17180.8	.08296
1958	.11644	73604.2	.23022	16891.8	.10360
1959	.17415	71885.5	.24844	16940.2	.09021
1960	.17298	75256.9	.29240	17069.0	.09868
1961	.12346	81994.1	.28788	16757.9	.08761
1962	.12987	81456.9	.29115	16507.6	.09192
1963	.16708	81232.6	.29535	16507.4	.09224
1964	.17040	82375.5	.29825	16695.6	.10223
1965	.12458	84102.7	.29714	17007.0	.10057
1966	.14411	85235.5	.29973	17472.0	.10969
1967	.18399	86626.2	.30346	18098.4	.12868
1968	.14511	89095.2	.30113	18836.6	.12935
1969	.14494	89862.7	.32084	19130.3	.12811
1970	.21484	90244.6	.35344	19265.6	.22160
1971	.14392	95229.9	.33064	19447.5	.14419
1972	.14338	95422.5	.32858	19492.0	.15629
1973	.17648	96174.8	.39304	19812.3	.20870
1974	.30221	84320.7	.21996	20846.7	.24694
1975	.24244	83105.6	.15496	21700.1	.13232
1976	.29732	84426.0	.40014	21973.6	.13203
1977	.21980	84527.4	.41772	22657.5	.05694
1978	.16265	89762.5	.48154	23195.4	.05165
1979	.27821	91559.4	.54451	24013.3	.20872
1980	.45218	106465.0	.62481	24635.8	.50539
1981	1.10488	87310.6	.78801	24624.7	.91457
1982	1.00000	88377.9	1.00000	24151.0	1.00000
1983	.78887	88395.5	1.06954	23004.4	.76471
1984	1.22143	84568.1	1.26631	21863.4	1.29876
1985	1.31225	84401.7	1.38065	20708.9	1.39161
1986	1.44412	82192.2	1.36869	19248.4	1.73484
1987	1.41054	81686.9	1.43938	17789.5	1.98740

See notes at end of table.

Continued--

Table 1--Time series data: Tornqvist indexes of prices and quantities--Continued

Year	QRE	PFD	QFD	PMAT	QMAT
<u>1982 = 100</u>					
1948	29502.3	0.59339	8413.0	0.31028	30163.2
1949	30858.7	.56486	8861.6	.29663	29154.3
1950	31699.5	.09937	8753.9	.29463	30862.1
1951	32281.2	.20342	9029.1	.31617	33491.2
1952	32767.4	.71078	9500.2	.33090	33741.0
1953	34021.8	.87402	9860.1	.30987	34142.9
1954	34553.1	.38229	9792.4	.32659	32683.4
1955	34966.3	.44721	9898.7	.29495	36942.1
1956	37675.0	.20860	10446.7	.29161	38150.4
1957	36065.5	.16844	9943.0	.28976	39712.2
1958	36308.8	.09089	10121.2	.31012	40058.5
1959	36533.5	.47708	10510.5	.31209	43538.7
1960	37035.6	.37383	11694.4	.30300	44448.2
1961	37161.4	.12491	16355.2	.32050	43326.0
1962	37416.6	.14384	16218.6	.33644	43522.8
1963	37677.2	.32337	16148.1	.34476	44912.8
1964	38061.1	.31388	16461.3	.34236	45390.5
1965	38240.9	.09633	16386.4	.34704	46536.2
1966	38379.0	.17220	16470.8	.36479	47997.6
1967	38512.5	.33028	16623.2	.36445	50660.0
1968	38703.8	.13283	16941.0	.35771	51913.7
1969	39126.3	.11253	16652.6	.36206	54004.8
1970	38981.7	.23297	16914.8	.38277	54606.7
1971	39034.8	.07226	22793.3	.39558	55122.2
1972	38992.7	.05134	23043.6	.42381	53953.3
1973	38958.2	.04550	23200.0	.57493	52554.1
1974	39224.7	.60825	18431.5	.62702	58476.6
1975	38257.7	.65437	17915.3	.65842	57761.4
1976	40020.0	.60414	18248.4	.68273	60691.5
1977	41834.6	.38739	17379.9	.72397	59001.3
1978	42022.5	.07176	17553.9	.73498	67591.9
1979	42794.0	.19232	18017.6	.82994	70835.5
1980	43167.6	.28750	38025.8	.93795	69760.5
1981	43410.8	1.87800	19894.0	1.01006	66962.4
1982	43336.2	1.00000	20890.8	1.00000	63702.0
1983	43227.8	.53299	22650.0	1.03252	62206.8
1984	43193.1	1.00821	19352.2	1.04147	66076.7
1985	43004.8	1.06976	20862.9	.98350	63074.5
1986	42738.8	.90047	20217.5	.96386	61943.8
1987	42359.6	.25419	21368.0	.98301	61926.4

See notes at end of table.

Continued--

Table 1--Time series data: Tornqvist indexes of prices and quantities--Continued

Year	PE	QE	PM	QM
<u>1982 = 100</u>				
1948	0.17180	6298.1	0.33925	24397.7
1949	.17483	6978.0	.32138	23112.7
1950	.17654	7154.1	.31837	24594.3
1951	.18218	7382.8	.34370	26895.8
1952	.17998	7717.5	.36271	26953.0
1953	.18434	7909.4	.33510	27221.4
1954	.18924	7868.5	.35468	25896.8
1955	.18866	8088.5	.31521	29726.1
1956	.19310	8089.1	.30989	30859.5
1957	.20052	7959.3	.30573	32417.5
1958	.20469	7753.1	.32960	32876.3
1959	.20454	7866.4	.33202	36079.1
1960	.20848	7967.2	.32021	36873.0
1961	.20976	8142.5	.34108	35703.9
1962	.20884	8269.4	.36066	35812.4
1963	.21083	8362.3	.37029	37054.5
1964	.20991	8536.7	.36760	37399.9
1965	.20978	8656.8	.37330	38398.0
1966	.21230	8798.9	.39423	39675.2
1967	.21717	8781.3	.39277	42151.9
1968	.21890	8793.8	.38432	43310.0
1969	.22320	8938.0	.38867	45174.6
1970	.22526	8945.3	.41301	45729.8
1971	.23474	8771.4	.42645	46303.0
1972	.23566	8677.7	.45991	45272.0
1973	.25634	8804.9	.63625	43941.9
1974	.36715	8612.2	.67760	49445.3
1975	.39668	9876.9	.70944	48084.2
1976	.42912	11094.8	.73186	50112.1
1977	.46620	11636.6	.77348	48210.7
1978	.49255	12177.4	.78083	55941.6
1979	.63896	11083.6	.86509	59770.7
1980	.87097	10798.3	.95020	58963.5
1981	.99631	10355.2	1.01256	56607.9
1982	1.00000	9775.0	1.00000	53927.0
1983	.97199	9626.7	1.04354	52583.3
1984	.97324	9722.2	1.05385	56321.8
1985	.96897	8861.0	.98681	54162.2
1986	.82423	8798.5	.98776	53102.8
1987	.78876	9318.4	1.01626	52667.6

See notes at end of table.

Continued--

Table 1--Time series data: Tornqvist indexes of prices and quantities--Continued

POUT	= Output price
QOUT	= Farm output
PCROPS	= Price of crop output
QCROPS	= Crop output
PANIMAL	= Price of livestock output
QANIMAL	= Livestock output
PHL	= Price of hired labor
QHL	= Hired labor
PSL	= Price of self-employed labor
QSL	= Self-employed labor
PKAP	= Price of capital
QKAP	= Capital stock, including farm machinery and equipment, farmland, service structures, breeding livestock, and inventories
PDE	= Price of durable equipment
QDE	= Durable equipment, including automobiles, trucks, tractors, and other farm machinery
PRE	= Price of farm real estate
QRE	= Farm real estate, including farmland and service structures
PFD	= Price of farm-produced durables
QFD	= Farm-produced durables, including beef cows, dairy cows, stocks of bulls, sheep, and breeding hogs, and farm inventories
PMAT	= Price of purchased material inputs
QMAT	= Purchased material inputs, including energy, agricultural chemicals, feed and seed, and miscellaneous
PE	= Price of energy
QE	= Energy inputs
PM	= Price of nonenergy material purchases
QM	= Nonenergy purchased material inputs

Table 2--Productivity growth rates and indexes

Year	Productivity indexes		Productivity growth rates	
	UPI	API	A/A	\hat{A}/A^*
<u>1982 = 100</u>				
1948	NA	NA	NA	NA
1949	55.89139	62.83098	NA	NA
1950	56.44843	62.51174	0.00997	-0.00508
1951	58.55536	63.99180	.03732	.02368
1952	60.08769	65.30065	.02617	.02045
1953	61.65327	66.80967	.02606	.02311
1954	64.43689	69.89168	.04515	.04613
1955	62.76516	67.67918	-.02594	-.03166
1956	61.57425	66.16111	-.01897	-.02243
1957	62.04603	66.31465	.00766	.00232
1958	66.48929	70.62245	.07161	.06496
1959	66.96210	71.16519	.00711	.00768
1960	66.85280	70.74606	-.00163	-.00589
1961	68.88254	72.17001	.03036	.02013
1962	70.49624	73.82517	.02343	.02293
1963	73.55481	76.74242	.04339	.03952
1964	73.67993	76.64567	.00170	-.00126
1965	76.45012	79.35261	.03760	.03532
1966	74.71083	77.15703	-.02275	-.02767
1967	77.95407	80.17066	.04341	.03906
1968	76.52547	78.50949	-.01833	-.02072
1969	78.86737	80.51099	.03060	.02549
1970	75.26815	76.74690	-.04564	-.04675
1971	82.03500	82.86757	.08990	.07975
1972	82.56081	83.35194	.00641	.00584
1973	87.06331	87.50557	.05454	.04983
1974	82.04806	83.83884	-.05760	-.04190
1975	88.42876	90.38440	.07777	.07807
1976	87.05969	88.72741	-.01548	-.01833
1977	94.66575	96.18062	.08737	.08400
1978	85.50545	87.14995	-.09676	-.09389
1979	88.78290	90.49121	.03833	.03834
1980	82.73786	82.43039	-.06809	-.08908
1981	99.30307	98.75127	.20021	.19800
1982	100.00000	100.00000	.00702	.01264
1983	86.50523	86.47801	-.13495	-.13522
1984	103.56316	102.55244	.19719	.18588
1985	110.69180	110.11570	.06883	.07375
1986	110.58528	109.92910	-.00096	-.00170
1987	110.76126	109.74673	.00159	-.00166

\hat{A}/A = Unadjusted productivity growth rate
 \hat{A}/A^* = Productivity growth rate, adjusted for capacity utilization
 UPI = Unadjusted productivity index
 API = Productivity index, adjusted for capacity utilization
 NA = Not available

Table 3--Estimation statistics: Quadratic, four-equation model

Parameter estimates			
Coefficient	Value	Standard error	T-Statistic
α_0	0.249933	0.118277	2.11311
α_M	1.605040	.070777	22.67740
α_T	-.002076	.001892	-1.09734
β_{MM}	-.034328	.013771	-2.49282
β_{Mt}	-.019720	.001212	-16.27380
α_K	-.182454	.244804	-.74531
α_S	-.366382	.114556	-3.19828
β_{KK}	.187230	.224604	.83360
β_{SS}	.825697	.230598	3.58068
β_{MK}	-.486722	.042186	-11.53750
β_{MS}	-.778063	.051722	-15.04320
β_{Kt}	-.002811	.002838	-.99050
β_{St}	.013654	.005548	2.46089

Single equation statistics			
Equation	R ²	CR-R ²	DW
G (EQN 15)	0.695025	0.554268	1.75283
M (EQN 16)	.822083	.801152	1.57671
L (EQN 17)	.391769	.229574	2.26276
R _{net} (EQN 20)	.420298	.289397	.87172

CR-R² = Corrected R²

DW = Durbin-Watson statistics

Table 4--Primal- and dual-capacity utilization measures

Year	Primal $CU = Y/Y^*$	Dual $CU^* = C^*/C$
1948	--	--
1949	0.699068	0.901037
1950	1.044536	1.036214
1951	1.053332	1.031584
1952	.699452	.918822
1953	.386098	.834178
1954	.904166	.974916
1955	.661782	.913410
1956	1.023561	1.011788
1957	.866201	.964891
1958	1.056971	1.021297
1959	.606250	.914699
1960	.571580	.917815
1961	1.152838	1.048069
1962	1.276798	1.055937
1963	.913534	.988826
1964	.860487	.979742
1965	1.476270	1.086683
1966	1.287627	1.055174
1967	.816126	.976242
1968	1.160394	1.031337
1969	1.147960	1.034436
1970	.510388	.925297
1971	1.410711	1.081369
1972	1.582665	1.103376
1973	2.212569	1.185419
1974	1.095225	1.007416
1975	1.995527	1.112925
1976	1.542276	1.063253
1977	2.491434	1.176303
1978	2.907477	1.244335
1979	2.347133	1.149715
1980	1.400948	1.054931
1981	-2.400286	.742164
1982	-2.142740	.784365
1983	-.325554	.877657
1984	-3.261493	.735484
1985	-4.401656	.690054
1986	-5.020259	.648669
1987	-4.619648	.669189

-- = Not applicable

Y = Actual output

Y^* = Optimal or capacity output, or that level of output which minimizes shortrun average total cost for a given stock of quasi-fixed inputs

C = Total costs, or the sum of factor costs, evaluated at market prices

C^* = Total shadow costs, or the sum of factor costs where quasi-fixed inputs are valued at their shadow prices rather than market prices

Appendix--Alternative Model Specifications and Their Empirical Estimation

In order to increase the robustness of the study results, alternative specifications of the basic quadratic, four-equation model and different measures of the key variables were used in econometric estimation.

Model Specifications

The basic model includes two quasi-fixed inputs, capital and self-employed labor, and two variable inputs, hired labor and material purchases. We expanded the number of quasi-fixed inputs to four, by disaggregating capital into three components, durable machinery and equipment, farm produced durables (that is, breeding livestock), and farm real estate. In addition, the purchased materials variable input was divided into energy and nonenergy material purchases, making a total of three variable inputs, including hired labor. Numerous specifications were estimated, depending on the number of variables included. In addition, more inputs implied more demand equations. Thus, we estimated four-, five-, and seven-equation alternative specifications of the basic four-equation model.

Multi-Output Models

The use of a single farm output variable, as in the basic model, assumes separability of outputs. Since most farm enterprises are multiproduct enterprises, this is a doubtful assumption. In order to test the significance of heterogeneous farm products, we estimated models using two rather than one output variable, crop and livestock products.

Stock Interaction Models

The basic model assumes no interaction between the quasi-fixed inputs; that is, changing the quantity of one quasi-fixed input is assumed to have no effect on the shadow price of another quasi-fixed input. Since this assumption appears unrealistic in a full equilibrium framework, we also constructed and estimated models permitting such interaction.

Price Equation Models

The basic four-equation model includes a shadow value equation (equation 20), but an alternative specification replaces the shadow value relationship with a price equation (equation 21). This alternative specification contains the same number of parameters and provides the same information as the basic specification. Empirical estimates should not substantially differ. To test this implication of the model, we estimated specifications with the price equation in place of the shadow value equation, as well as five-equation models containing both price and shadow value equations.

Translog Models

We selected the quadratic specification for our basic model for two reasons. First, most of the existing capacity utilization literature uses quadratic specifications. In order to compare our results with those of earlier studies, we selected the quadratic specification. Second, quadratic models yield determinate solutions for optimal output, an important consideration for deriving primal capacity utilization measures. Translog models do not provide a closed form solution for optimal output, requiring numerical procedures for proxying optimal output. However, the production literature makes wide use of translog model specifications. Thus, we also developed and estimated translog models, though without measures of optimal output.

Dynamic Models

Although the presence of quasi-fixed inputs clearly has dynamic implications, the basic model remains essentially static, since the process of dynamic adjustment toward longrun steady state equilibrium is ignored. A dynamic specification is not necessary for deriving measures of capacity utilization, shadow

prices, and capacity utilization adjusted measures of productivity growth. To study the implications of a fully dynamic model, we developed and estimated dynamic models, where the change in quasi-fixed inputs enters as an argument in the restricted cost function and the farm operator must minimize the present value of total costs, including those associated with adjusting stocks of quasi-fixed factors.

Model Estimations

We estimated six broad categories of alternative model specifications:

Disaggregated Input Models

Parameter estimates were far less precise, and negative R^2 's affected some equations. Disaggregated input models yielded unstable, unreliable, or invalid shadow prices, the shadow price ratios for farm real estate were exaggerated and implausible. The shadow price ratios for durable machinery and equipment, farm produced durables, and self-employed labor were often negative or realistically low.

Estimated adjusted productivity growth was close to zero, a reflection of the unstable shadow price relationships, and did not correspond to the results of other estimations. However, the magnitude and periodicity of estimated dual-capacity utilization matched the findings of the basic model.

Multi-Output Models

A quadratic, four-equation model, with 2 outputs, 2 quasi-fixed inputs, and 2 variable inputs requires the estimation of 19 parameters, 6 more than the basic, 1-output model. The additional parameters measure interaction between the outputs. Excellent results were achieved. Ten out of 19 parameters were statistically significant. Of the six interaction parameters, four were significant. Of the original 13 parameters, 11 worsened in overall precision, 2 improved, 3 changed sign, and 3 became insignificant, a reflection of the additional parameters estimated. All R^2 's were positive and marginally improved compared with the basic model. Durbin-Watson statistics worsened, particularly for the variable cost and purchased input equations.

With one exception, measures of dual-capacity utilization, shadow price ratios, and adjusted productivity growth were not significantly different from those of the basic model. Adjusted productivity growth averaged 1.6713 percent per year during the entire 1949-87 estimation period, compared with 1.6675 percent for the basic single output model. Disequilibrium amounted to 0.3381 percent per year on average during the same period, or 16.83 percent of observed, unadjusted productivity growth. The multioutput model did show an increase in the shadow price ratio for self-employed labor after 1970, a finding not found in other estimations. On the whole, however, the multioutput model strongly supports the findings of the basic, 1-output model.

Stock Interaction Models

While the empirical estimates of stock interaction models generally conform to those of the basic model, parameter estimates are less precise and capacity utilization measures are unreliable and possibly invalid. In none of the attempted estimations was the stock interaction parameter significant. Moreover, in all cases, inclusion of a stock interaction parameter reduced the precision of other estimated parameters. Measures of capacity utilization were unstable, contradicted the results of models without a stock interaction parameter, and were not consistent across different stock interaction estimations. However, estimates of shadow price ratios and productivity growth were quite close to those of the basic model.

Price Equation Models

Price equation models provided statistically excellent results, which were nearly identical to those of the basic model using a shadow value equation. Nine out of 13 parameters were statistically significant. Compared with the basic model, eight parameters improved in levels of significance and five worsened but only marginally. R^2 s and Durbin-Watson statistics were not significantly different.

The magnitudes and cyclic patterns of dual-capacity utilization measures very closely matched those of the basic model. For the 1949-87 estimation period, dual-capacity utilization averaged 0.9635, compared with 0.9732 for the basic model. Dual-capacity utilization averaged 1.0157 for 1949-80 and 0.7248 for 1981-87. Primal-capacity utilization measures were less volatile in price models, but periodic patterns were identical.

The values, ranges, and periodic patterns of shadow price ratios for capital and self-employed labor were quite close to those of the basic model but marginally lower. The capital shadow price ratio averaged 1.2373 (compared with 1.2559) for the entire 1949-87 estimation period, but fell from an average 1.3834 for 1949-80 to an average 0.5695 for 1981-87. The shadow price ratio for self-employed labor averaged 0.6137 (compared with 0.6341) during the 1949-87 period, falling from 0.6463 for 1949-80 to 0.4646 for 1981-87.

Productivity growth rates, moving average growth rates, disequilibrium measures, and resulting productivity indexes were nearly identical. Observed periodic patterns were the same. Over the entire 1949-87 period, adjusted productivity growth averaged 1.6479 percent per year, compared with 1.6675 percent per year found using the basic model. Adjusted productivity rose from an average 0.9548 percent per year for 1949-80 to 4.7172 percent per year for 1981-87. Disequilibrium amounted to 0.3615 percent per year for 1949-87, or 17.99 percent of unadjusted productivity growth. These findings are essentially the same as those of the basic model.

Translog Models

Attempts to estimate translog models were not successful. Levels of statistical significance were low, and negative R^2 s appeared in some translog specifications. Dual-capacity utilization measures were not consistent across different translog specifications and differed sharply from those of quadratic models. Shadow price ratios were conceptually unacceptable and contradicted those obtained from quadratic models. The shadow price ratio of self-employed labor was always negative, and the capital shadow price ratio was negative for 20 years out of the entire estimation period. Adjusted productivity growth was negative until 1969. These poor results may stem from a fundamental misspecification in the translog model.

Dynamic Models

The dynamic model appears to be misspecified, since negative R^2 s appeared in all estimations. However, dynamic specifications did have two interesting properties. First, the precision of parameter estimates was quite high. The basic dynamic model is a five-equation model, with 15 parameters, 2 more than the basic, static form. The additional parameters are adjustment coefficients for capital and self-employed labor. A full 12 of the 15 parameters were statistically significant, and both adjustment coefficients were significant, suggesting that adjustment of quasi-fixed inputs is important. Second, the adjustment coefficients appear quite plausible: self-employed labor adjusts far more slowly than capital. Using a 4-percent discount rate, the adjustment coefficients of capital and self-employed labor were 0.72 and 0.10, respectively.



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